THE NUCLEAR DEPENDENCE OF $R=\sigma_L/\sigma_T$ IN DEEP INELASTIC SCATTERING

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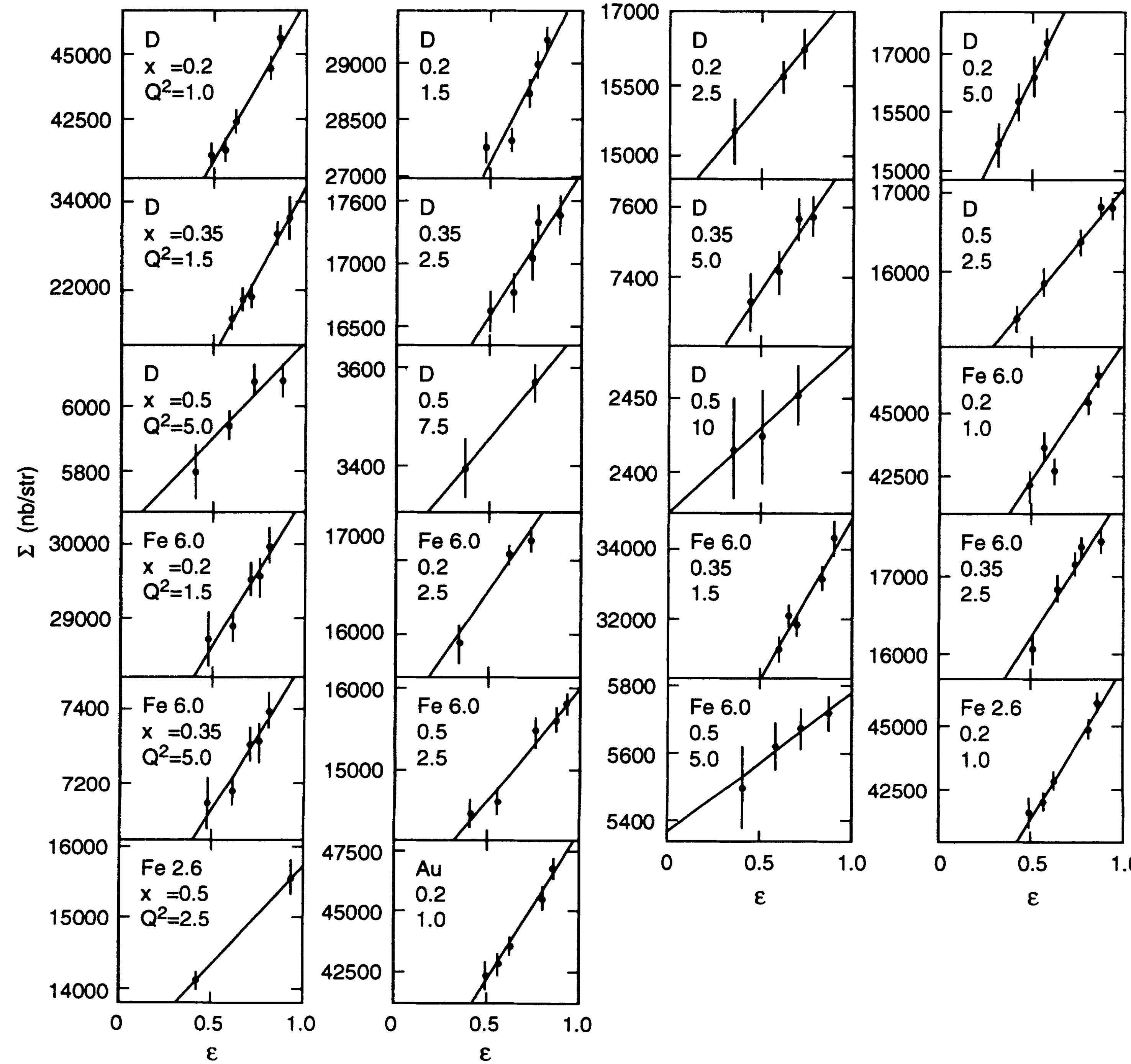
R(X,Q²)

$$\frac{d\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T(x,Q^2) + \varepsilon\sigma_L(x,Q^2)\right]$$

$$\boxed{R(x,Q^2) = \frac{\sigma_L(x,Q^2)}{\sigma_T(x,Q^2)}}$$



Dasu et al., PRD49, 5641(1994)

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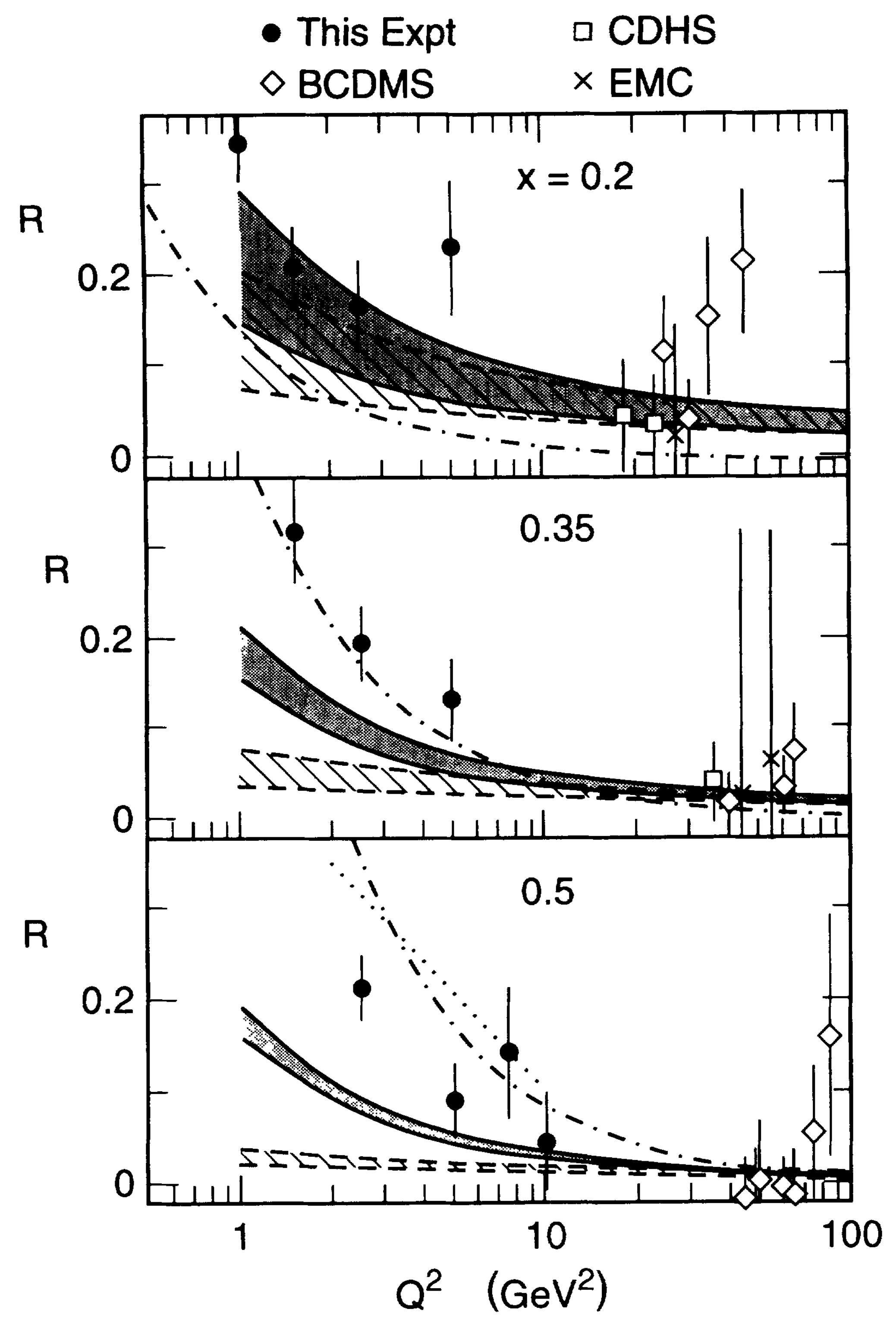
$$\boxed{R(x,Q^2) = \frac{\sigma_L(x,Q^2)}{\sigma_T(x,Q^2)}}$$

In a model with:

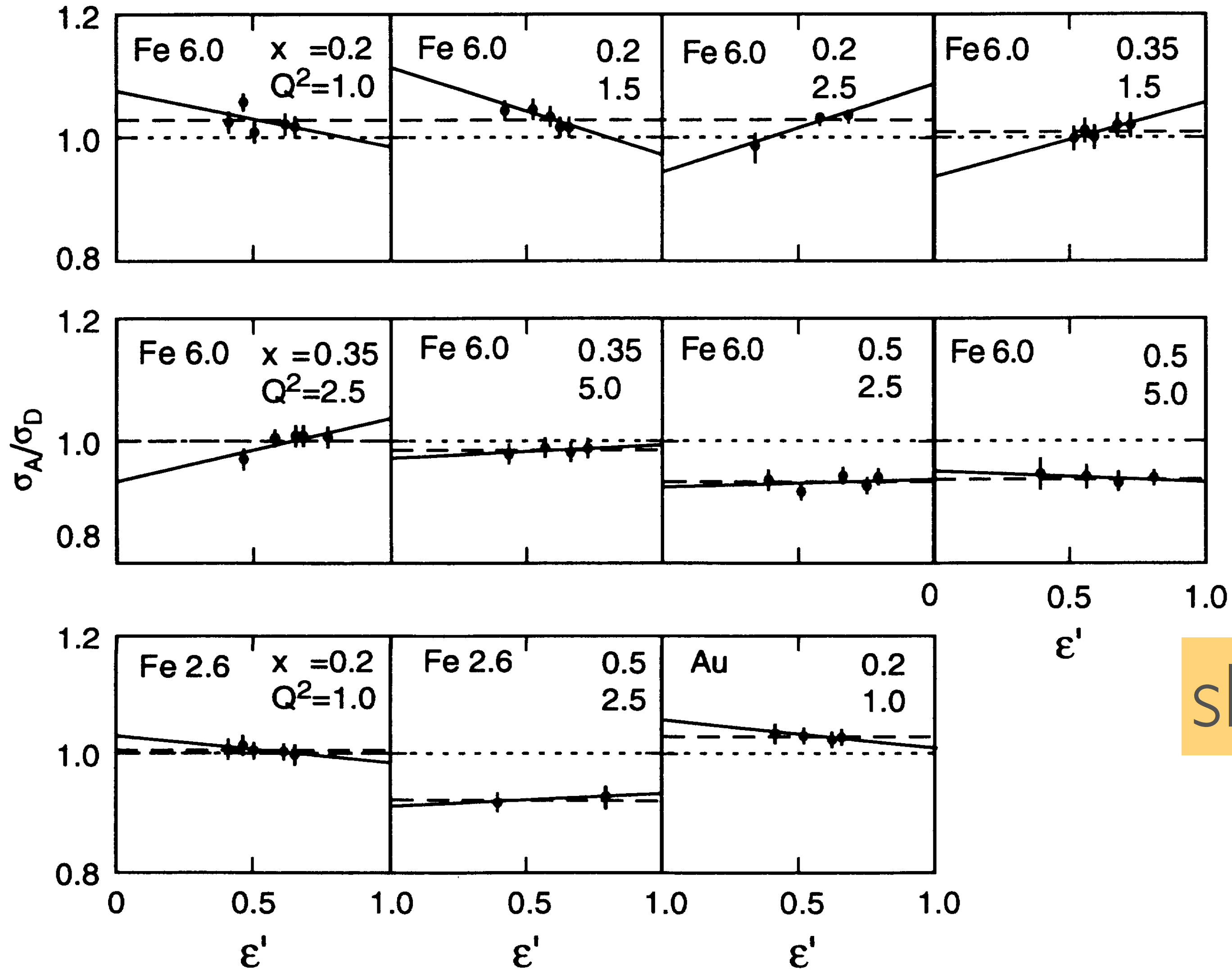
a) spin-1/2 partons: R should be small and decreasing rapidly with Q^2

b) spin-0 partons: R should be large and increasing with Q^2

Dasu et al., PRD49, 5641(1994)



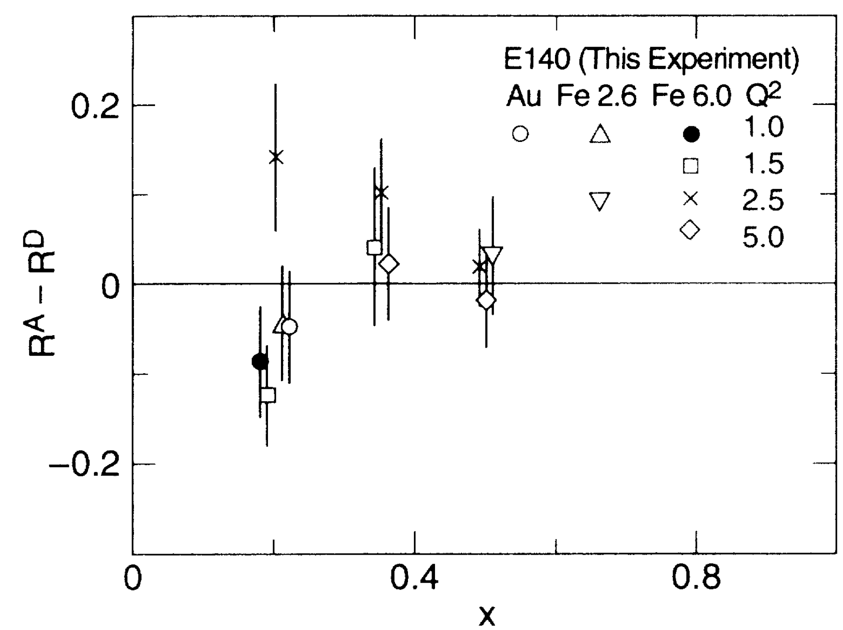
ACCESS TO NUCLEAR DEPENDENCE OF R



Dasu et al., PRD49, 5641(1994)

FIG. 13. The fits to the differential cross section ratio σ_A/σ_D versus $\epsilon' = \epsilon/(1 + R^D)$ are shown for each (x, Q^2) point. The errors on the cross section include statistical and point-to-point systematic contributions added in quadrature.

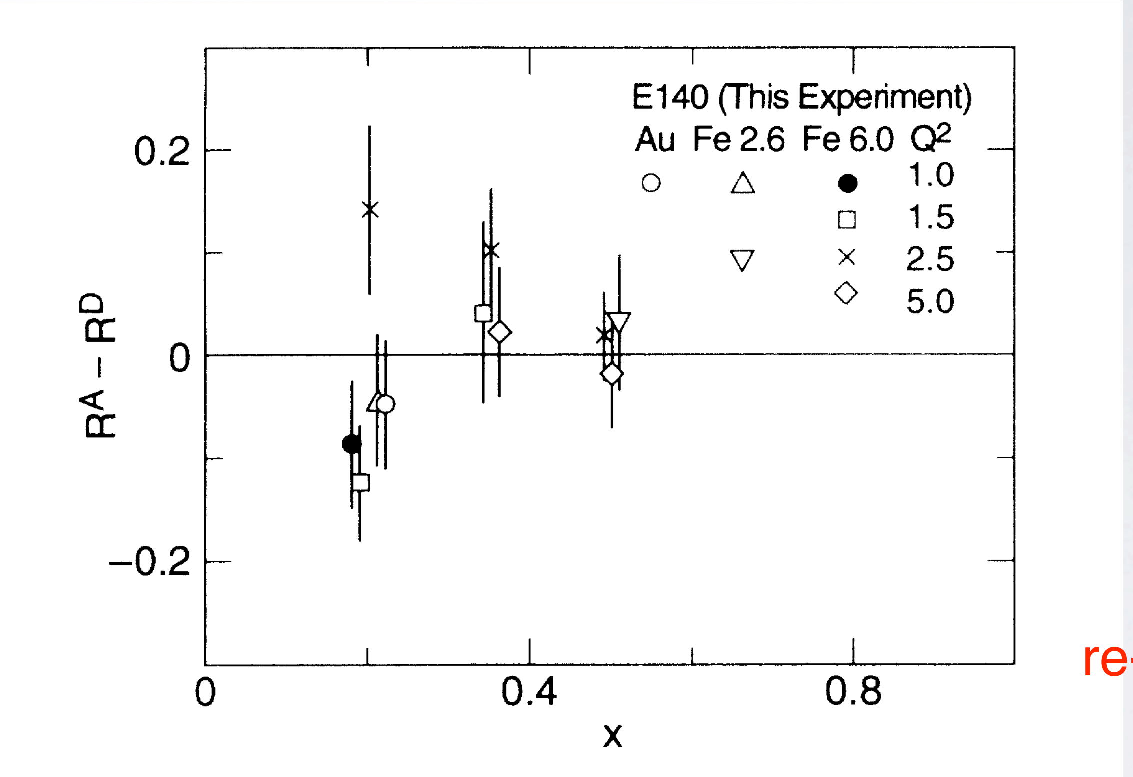
slopes $\Rightarrow$ R_A-R_D



Nuclear higher twist effects and spin-0 constituents in nuclei: same as in free nucleons

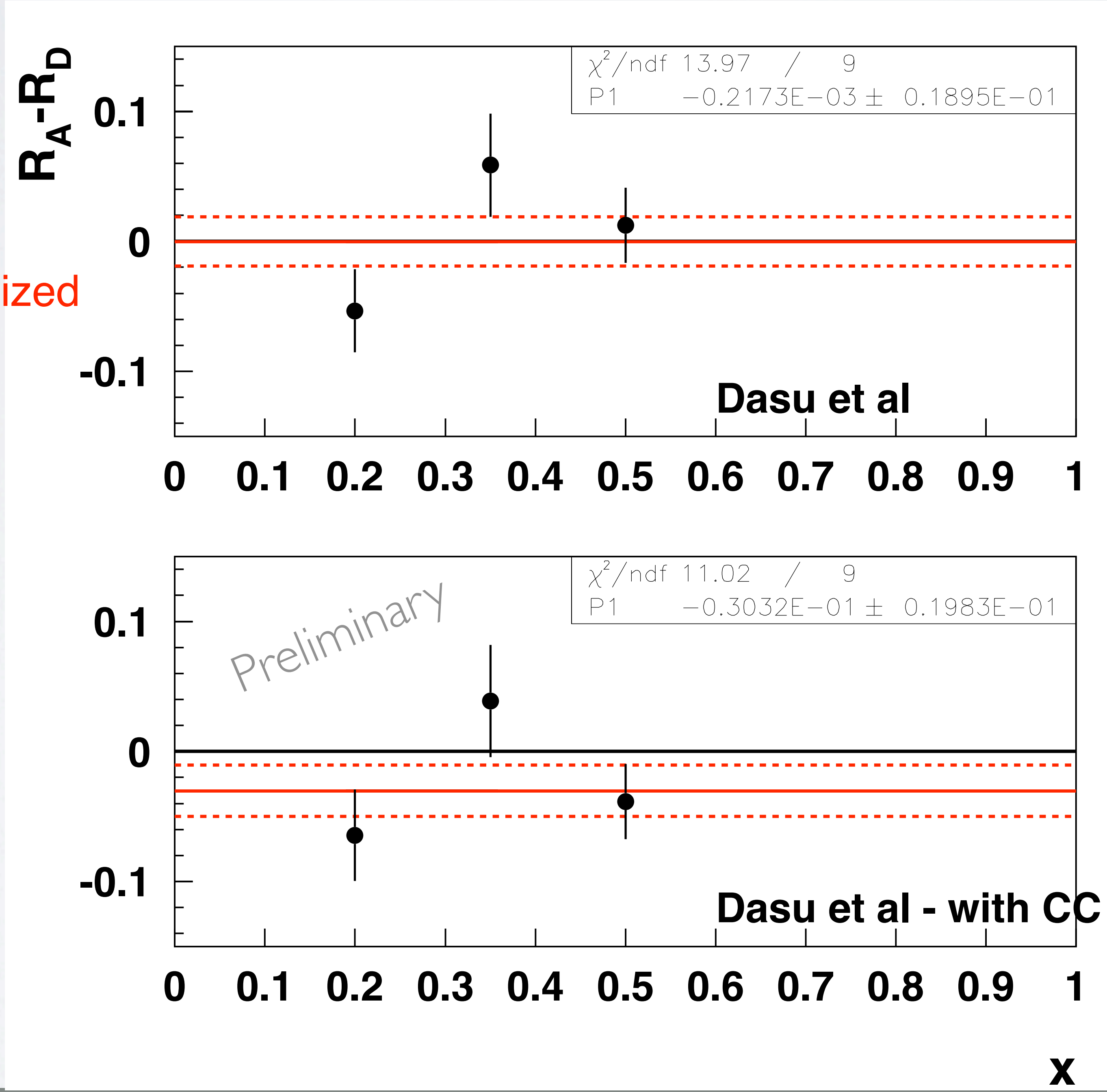
$\Leftarrow$ R_A-R_D=0

ACCESS TO NUCLEAR DEPENDENCE OF R



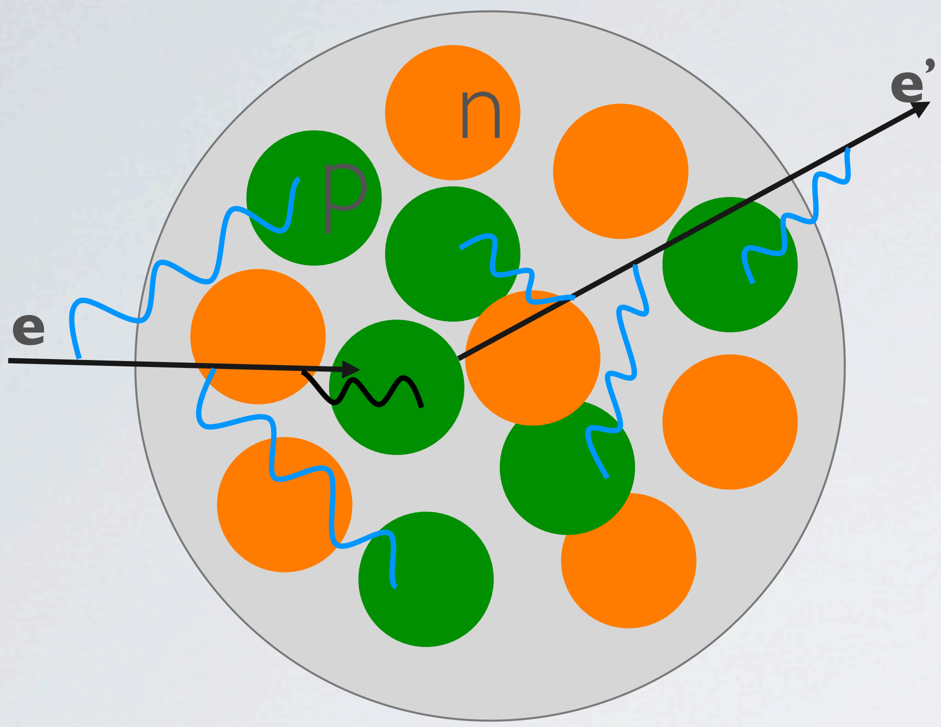
Dasu et al., PRD49, 5641(1994)

re-analysized



A non-trivial effect in R_A-R_D arises after applying Coulomb corrections

HEAVY NUCLEI AND COULOMB DISTORTION



Exchange of **one or more (soft) photons** with the nucleus, in addition to the **one hard photon** exchanged with a nucleon

Incident (scattered) electrons are accelerated (decelerated) in the Coulomb well of the nucleus.

$$\cancel{\sigma_{tot}^{PWBA} = \sigma_{Mott}\, S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta)}$$

$$\sigma_{tot}^{DWBA}$$

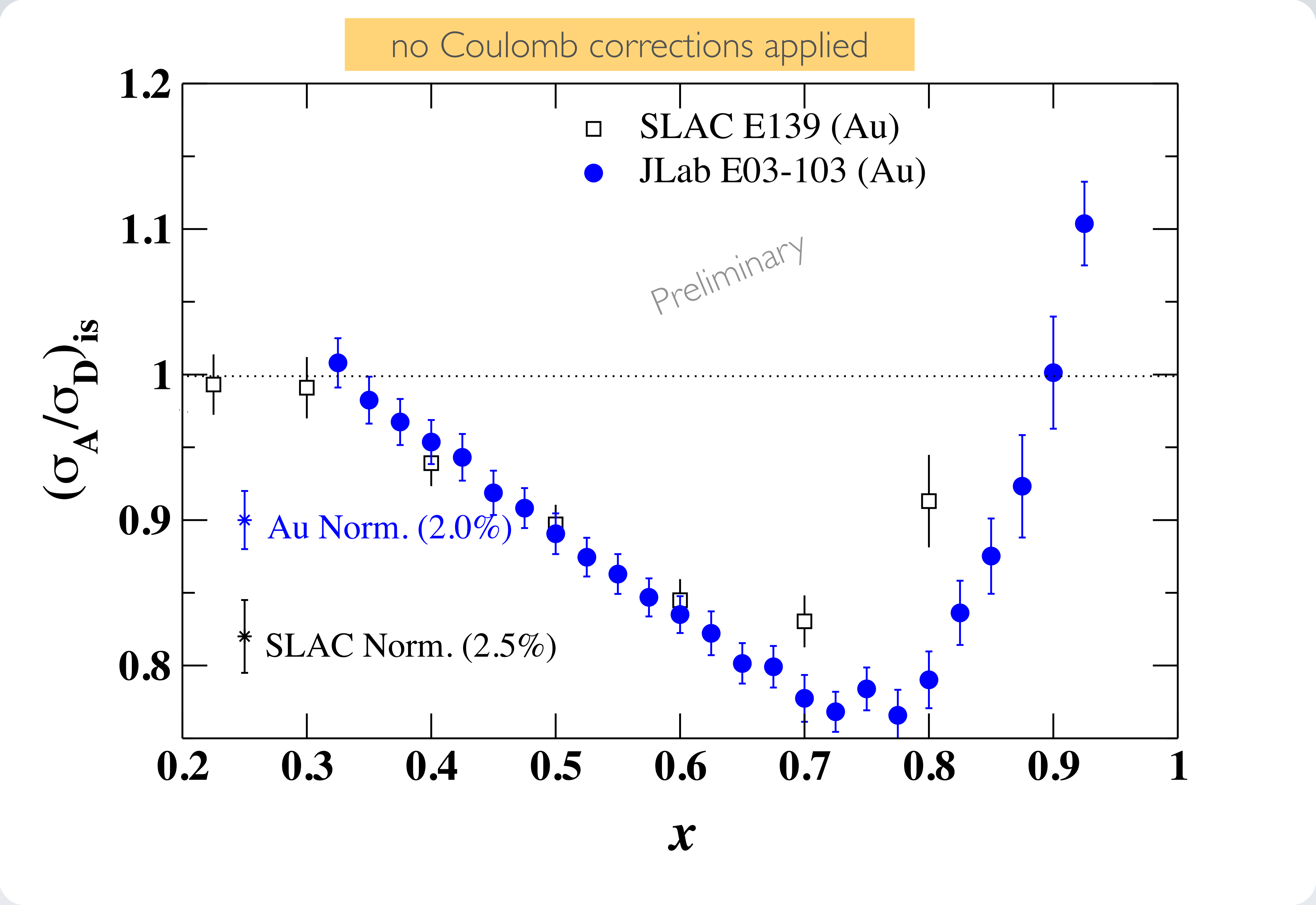
- Focusing of the electron wave function
- Change of the electron momentum

Effective Momentum Approximation (EMA)

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)

$$\left.\begin{aligned} E &\rightarrow E + \bar{V} \\ E_p &\rightarrow E_p + \bar{V} \end{aligned}\right\} \quad Q^2_{eff} = 4(E+\bar{V})(E_p+\bar{V})\sin^2(\frac{\theta}{2})$$

COULOMB DISTORTION EFFECT ON E03-103



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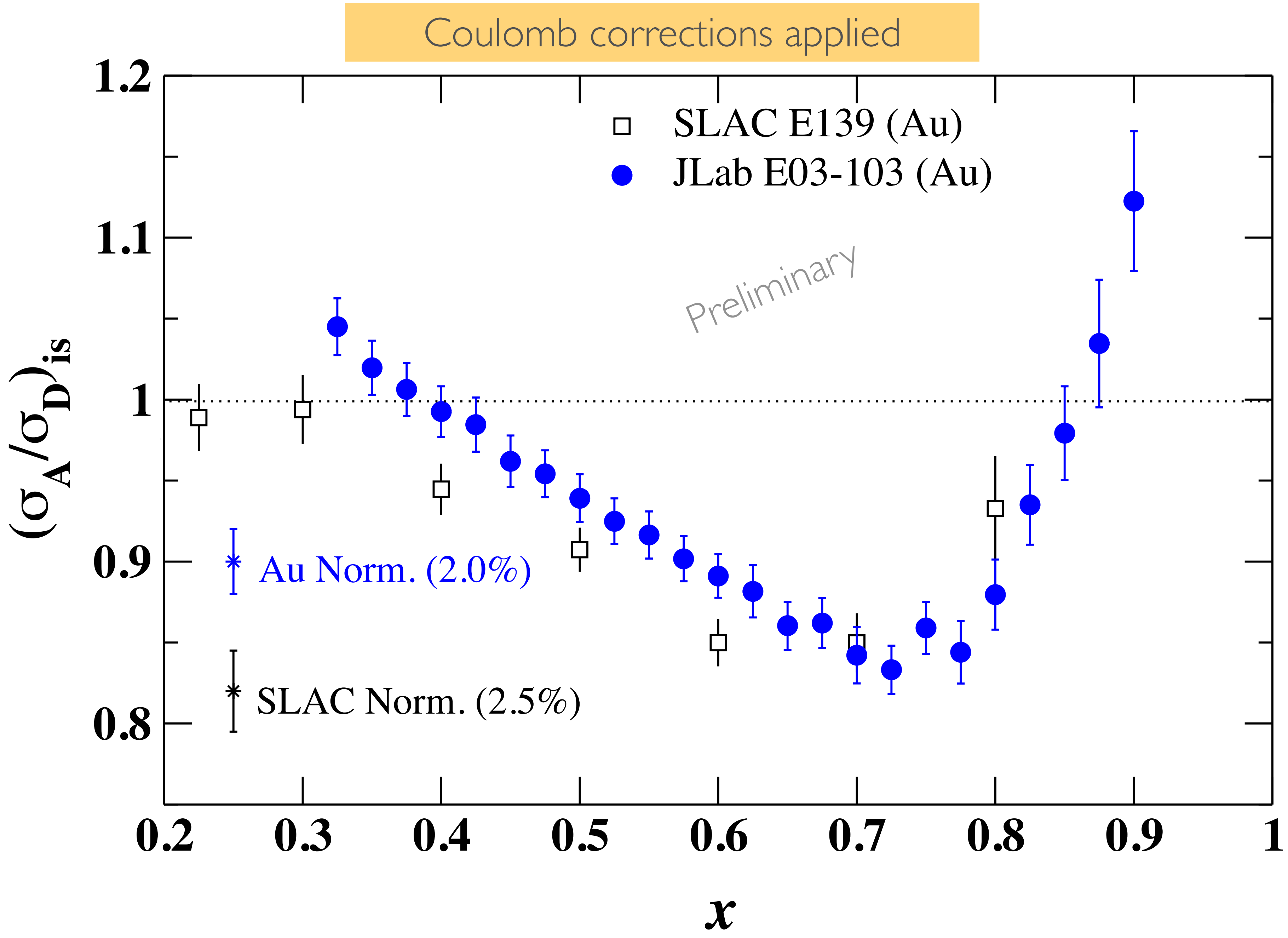
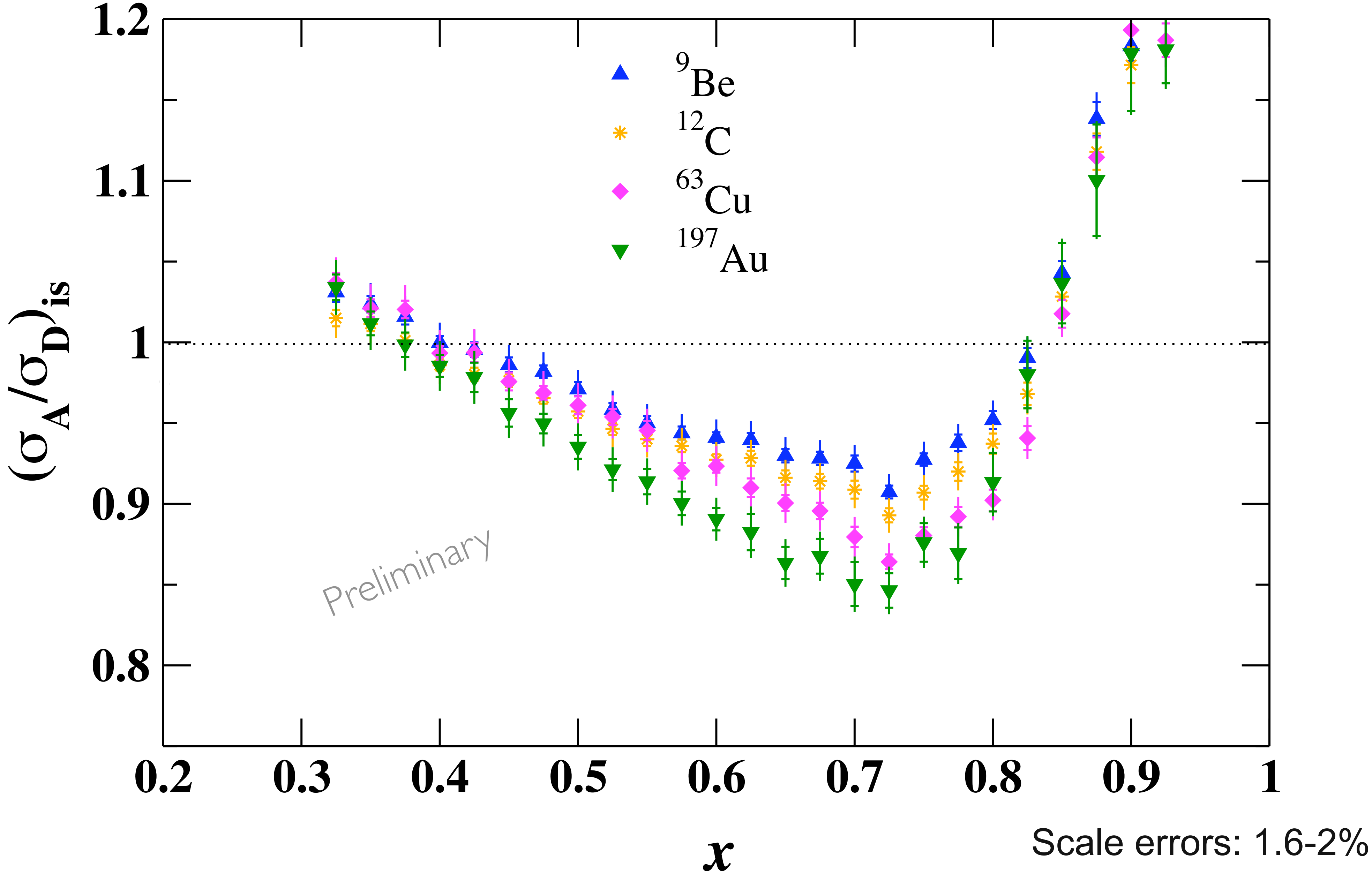


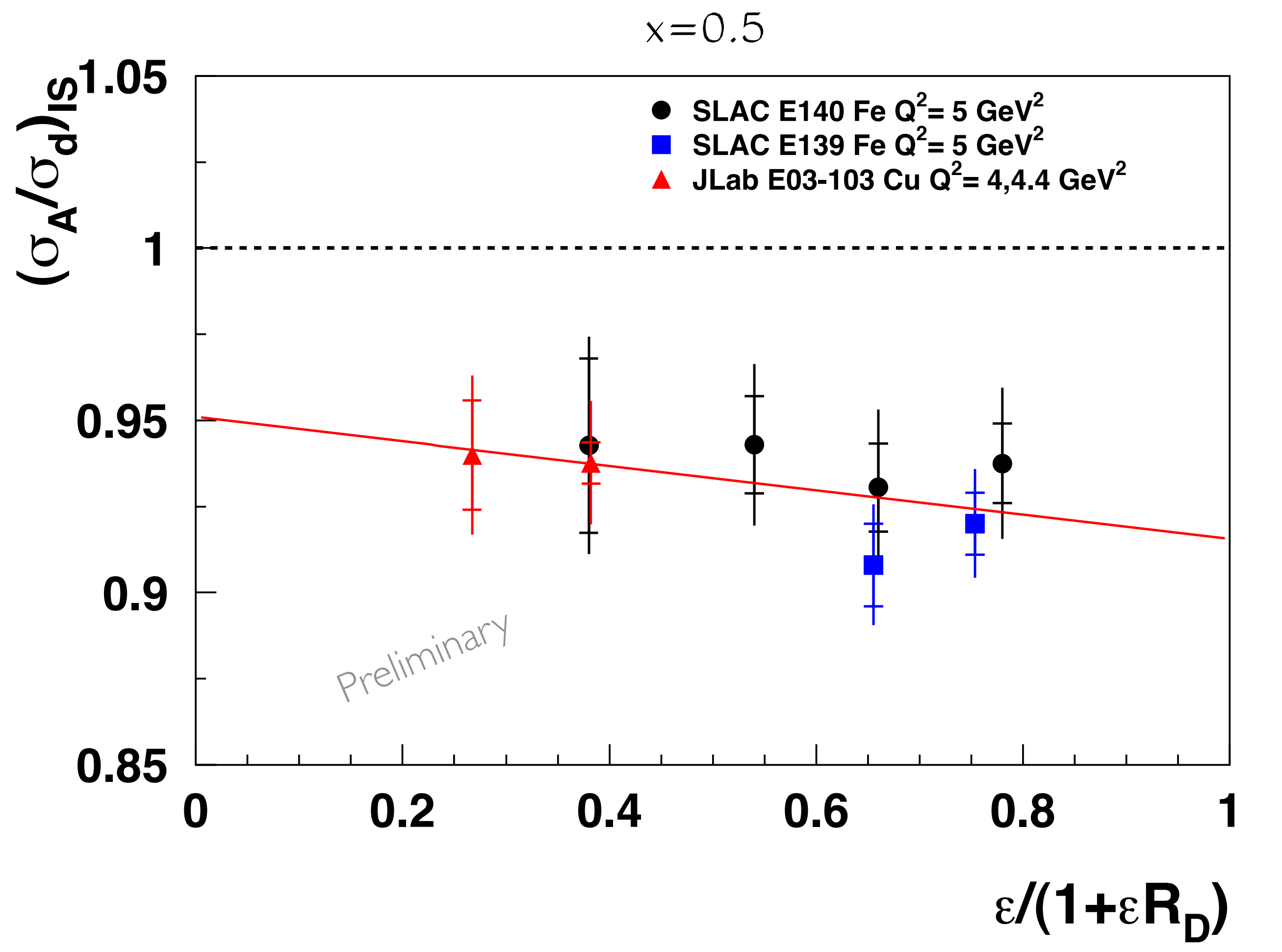
HEAVIER NUCLEI DATA FROM E03-103



ACCESS TO NUCLEAR DEPENDENCE OF R

Iron-Copper

No Coulomb corrections applied

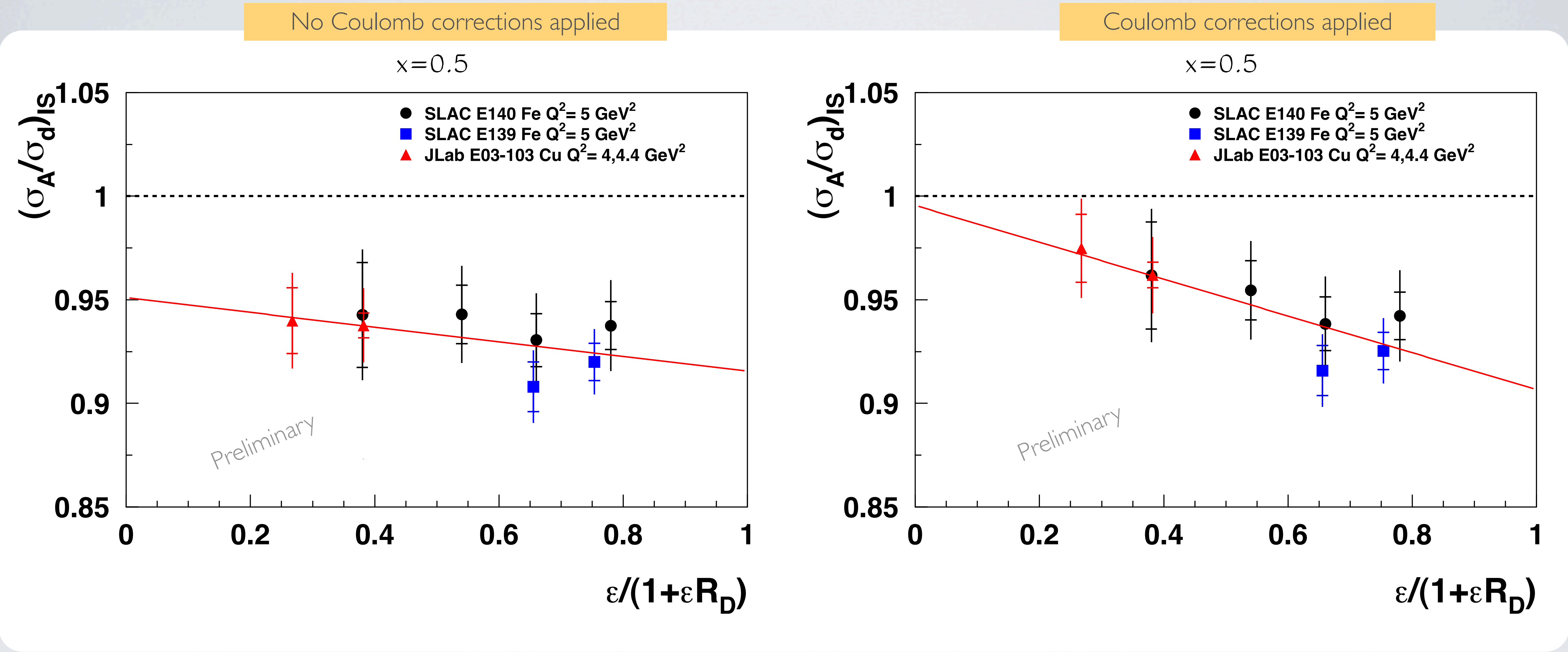


slopes $\Rightarrow R_A - R_D$

$R_A - R_D = 0 \Rightarrow$ **Nuclear higher twist effects and spin-0 constituents in nuclei: same as in free nucleons**

ACCESS TO NUCLEAR DEPENDENCE OF R

Iron-Copper

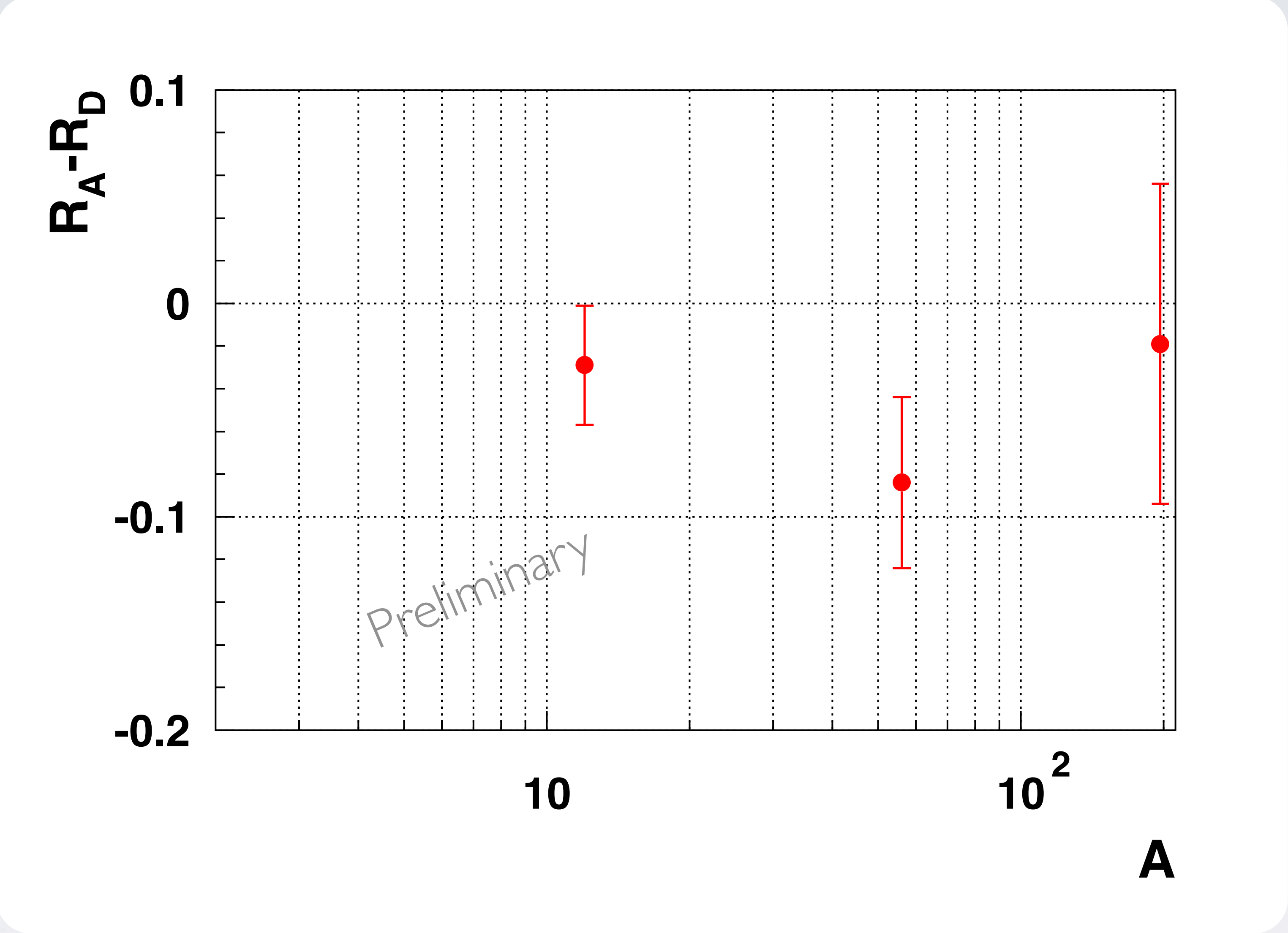


New data from JLab E03-103: access to lower ε

After coulomb corrections: $R_A - R_D = -0.08 \pm 0.04$

Access to nuclear dependence of R

Hint of an A-dependence in R in Copper-Iron



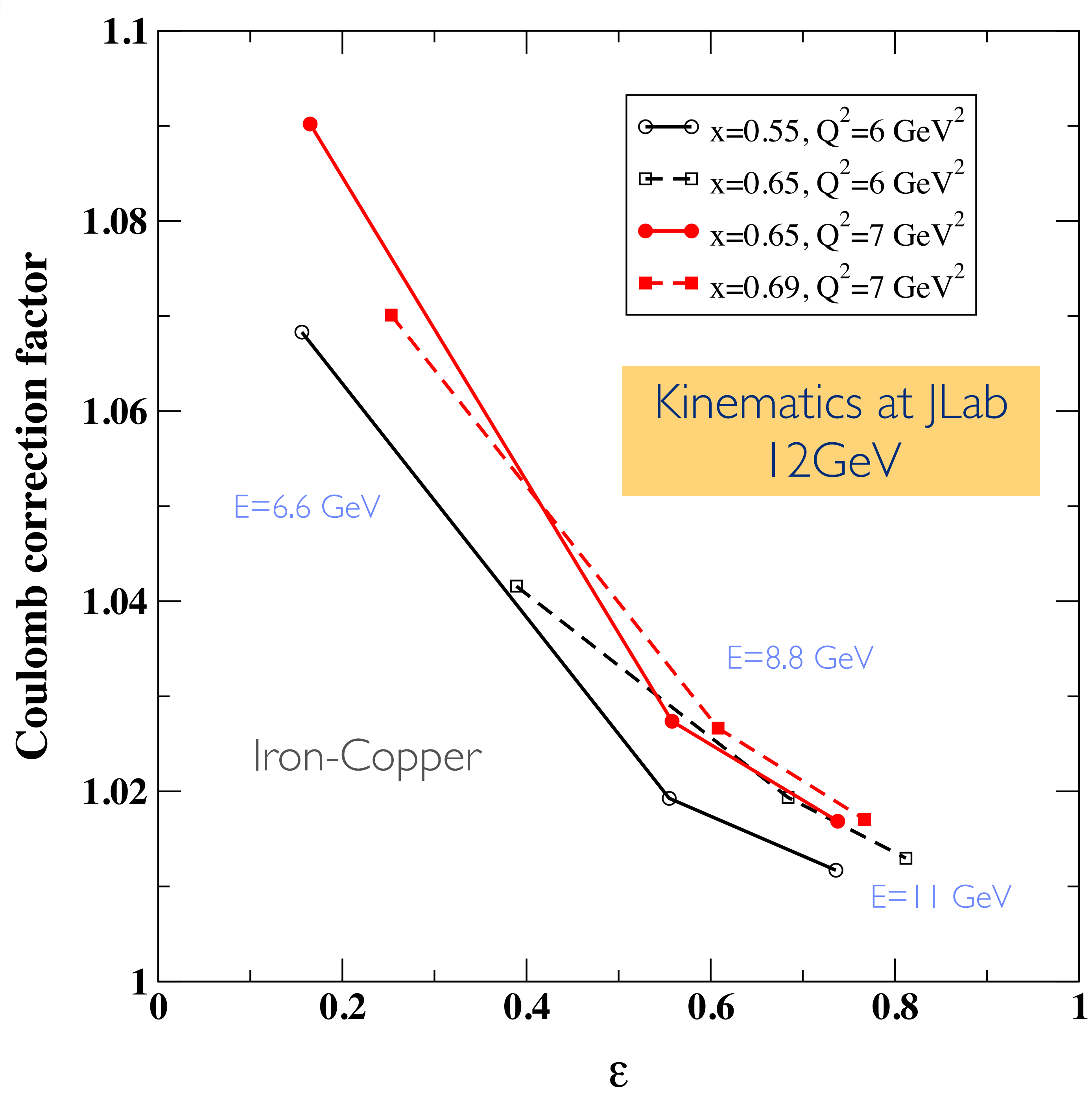
After taking into account the normalization uncertainties from each experiment

COULOMB DISTORTION: ε-DEPENDENCE

The ε-dependence of the Coulomb distortion has effect on the extraction of R in nuclei.

$$\boxed{\epsilon = \frac{1}{1 + 2\left[1 + \frac{\nu^2}{Q^2}\tan^2\left(\frac{\theta}{2}\right)\right]}}$$

$$\theta = 0^\circ \rightarrow \epsilon = 1$$
$$\theta = 180^\circ \rightarrow \epsilon = 0$$



EXTRACTION OF R_{NM}

✓ Need several ε values with enough nuclei coverage

✓ Remove ^{3}He data from the extrapolation

At constant Q^2 and x:

➡ at each ε, fit the cross section ratios σ_A / σ_D vs. $A^{-1/3}$ or ϱ

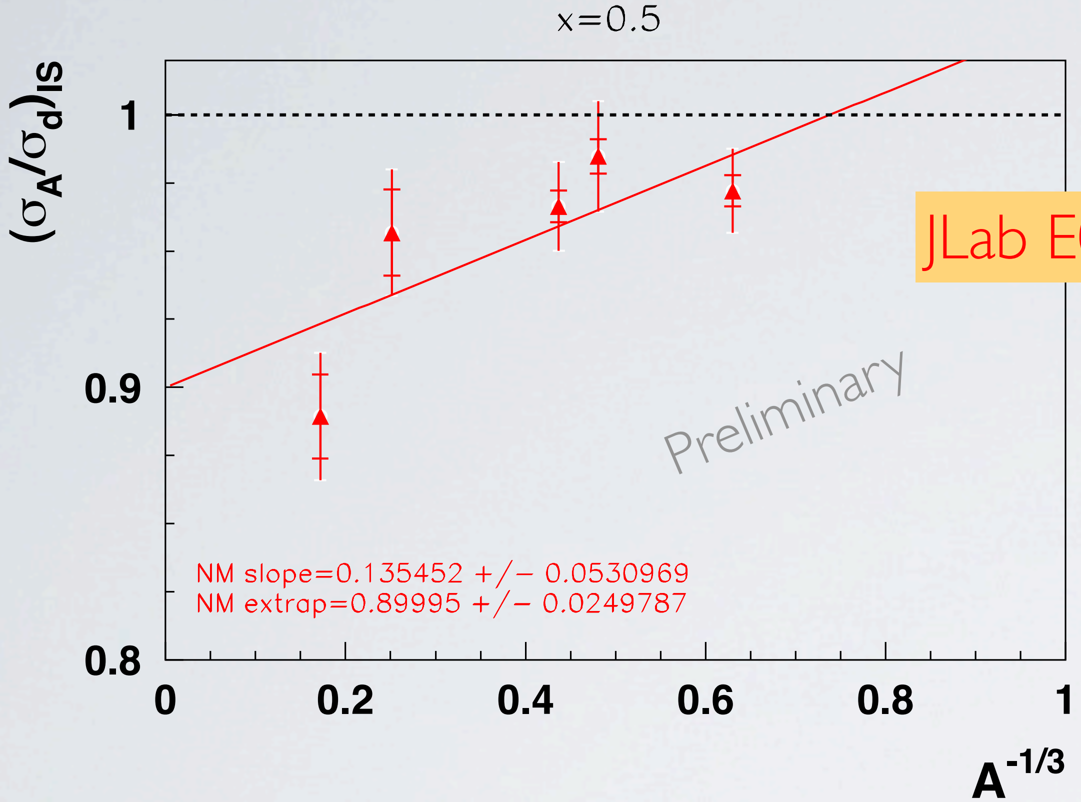
➡ extrapolate the fit to infinite nuclear matter: $A^{-1/3} \rightarrow 0$ or $\varrho \rightarrow 0.17$. Get σ_{NM} / σ_D for each ε.

➡ plot nuclear matter cross section ratios vs. $\varepsilon/(1+\varepsilon R_D)$

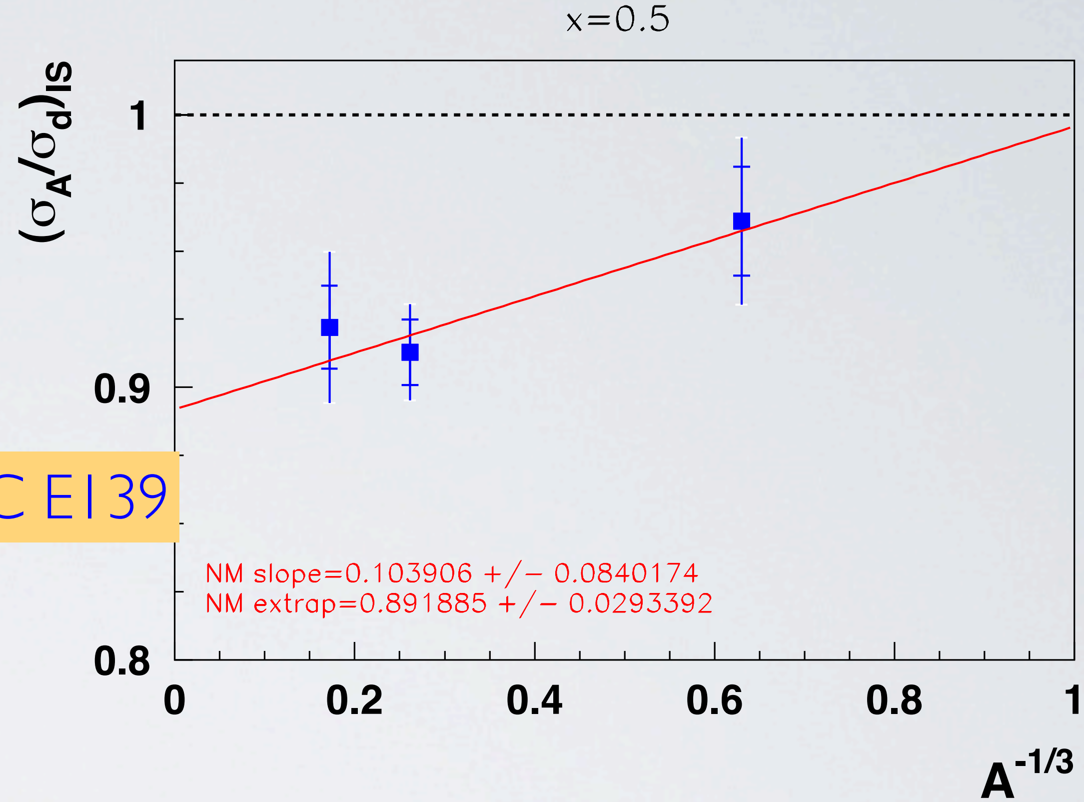
➡ slope of the fit gives $R_{NM}-R_D$

R_{NM}: X=0.5, NO COULOMB CORRECTION

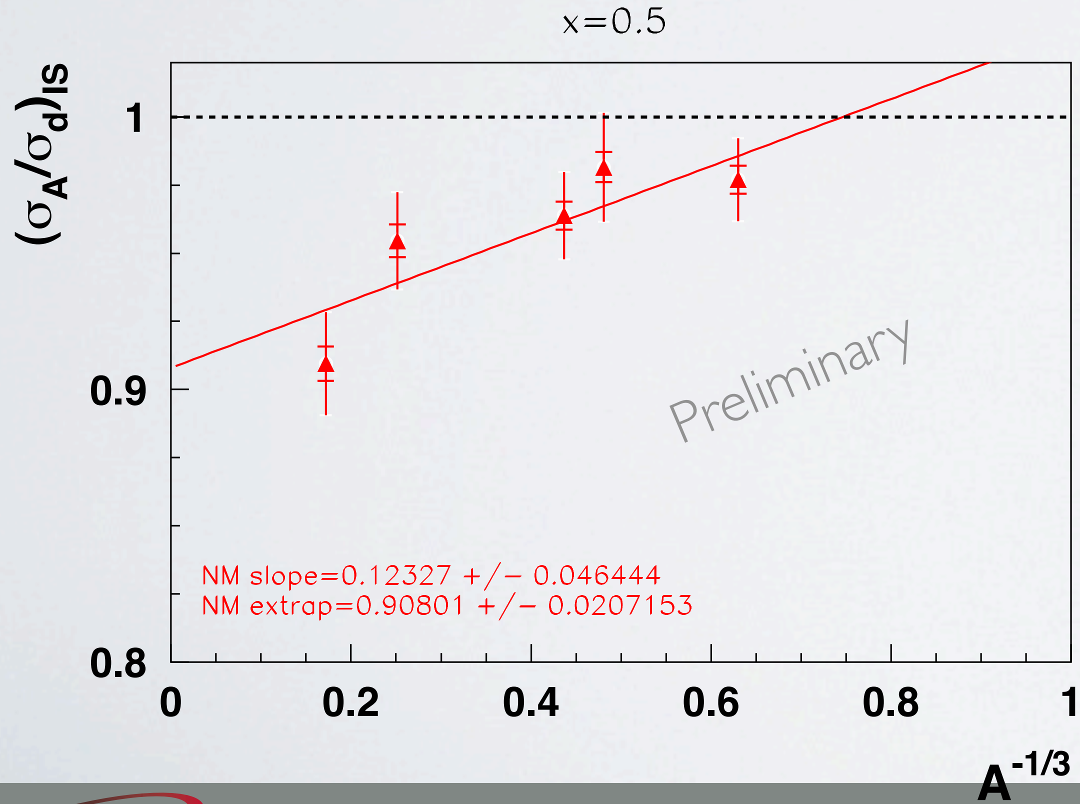
A-dependence

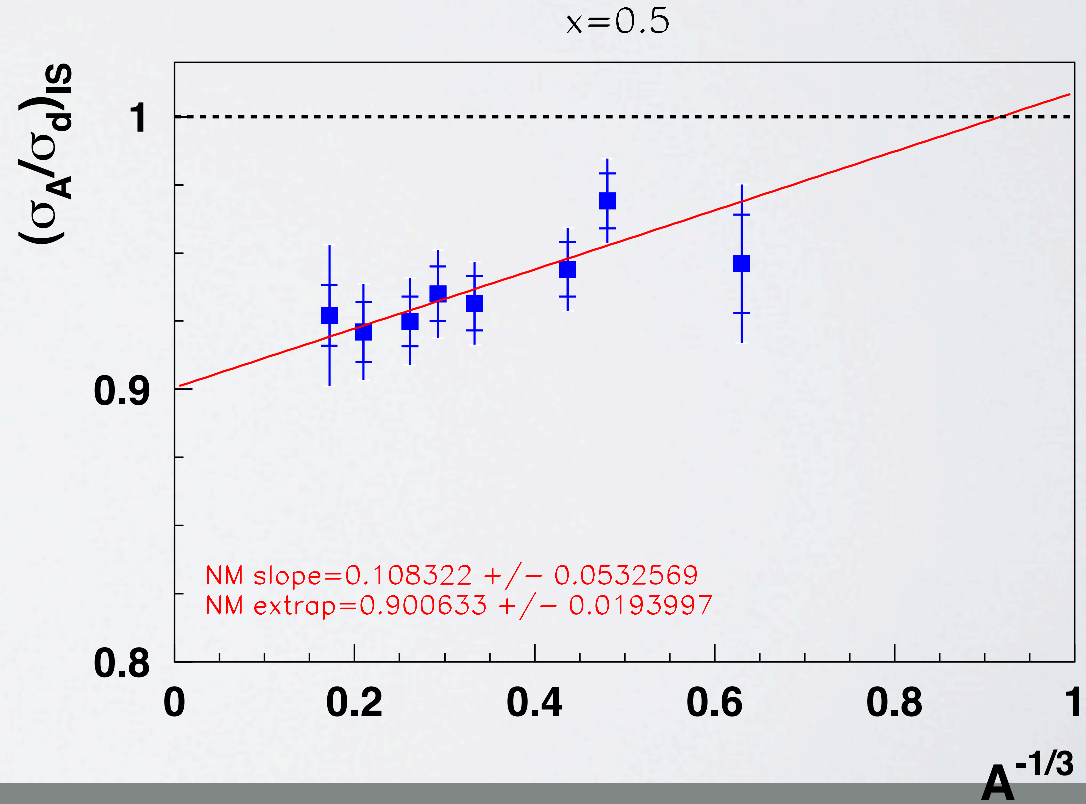


JLab E03-103



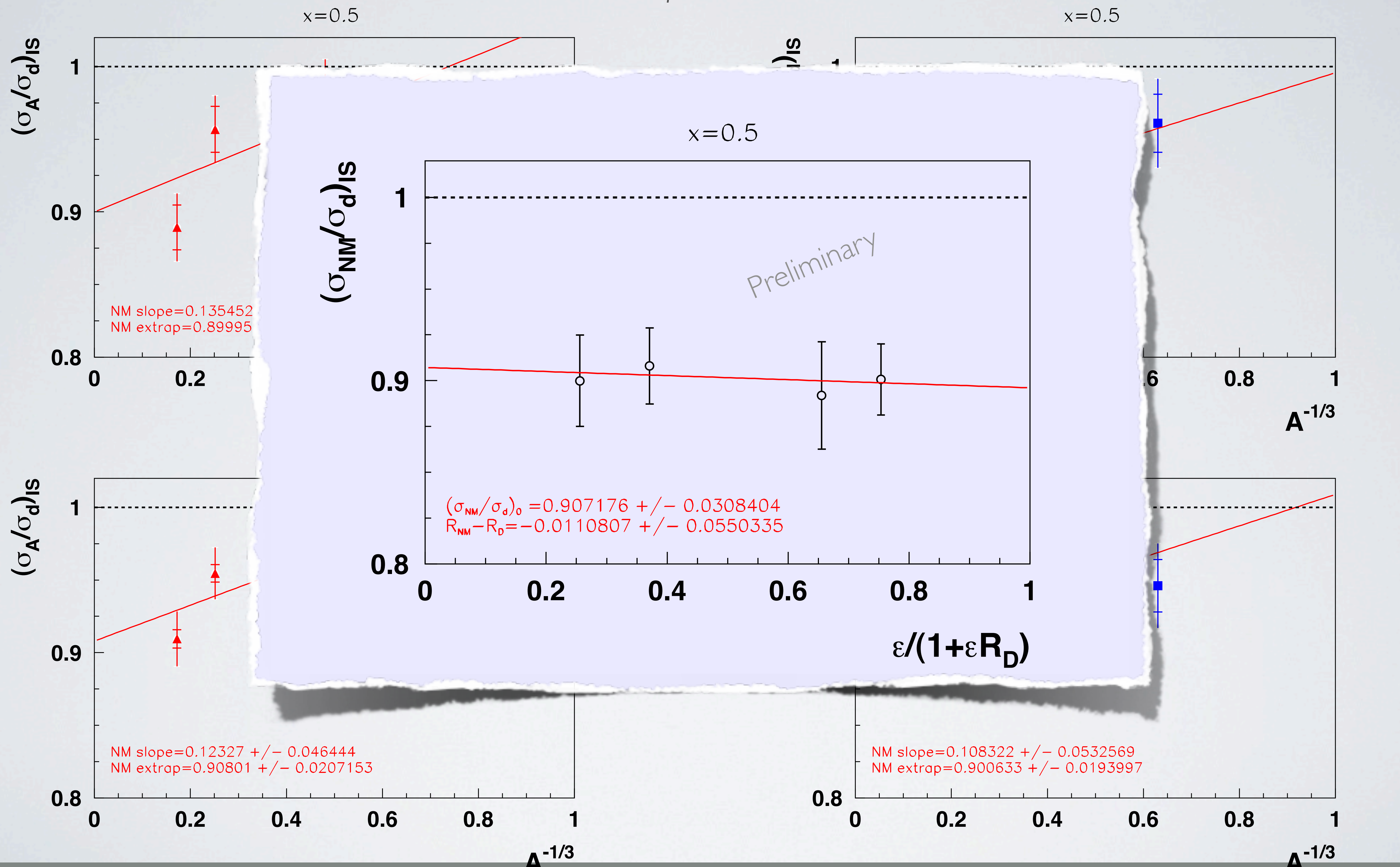
SLAC E139





R_{NM}: X=0.5, NO COULOMB CORRECTION

A-dependence



R_{NM}: X=0.5, COULOMB CORRECTION

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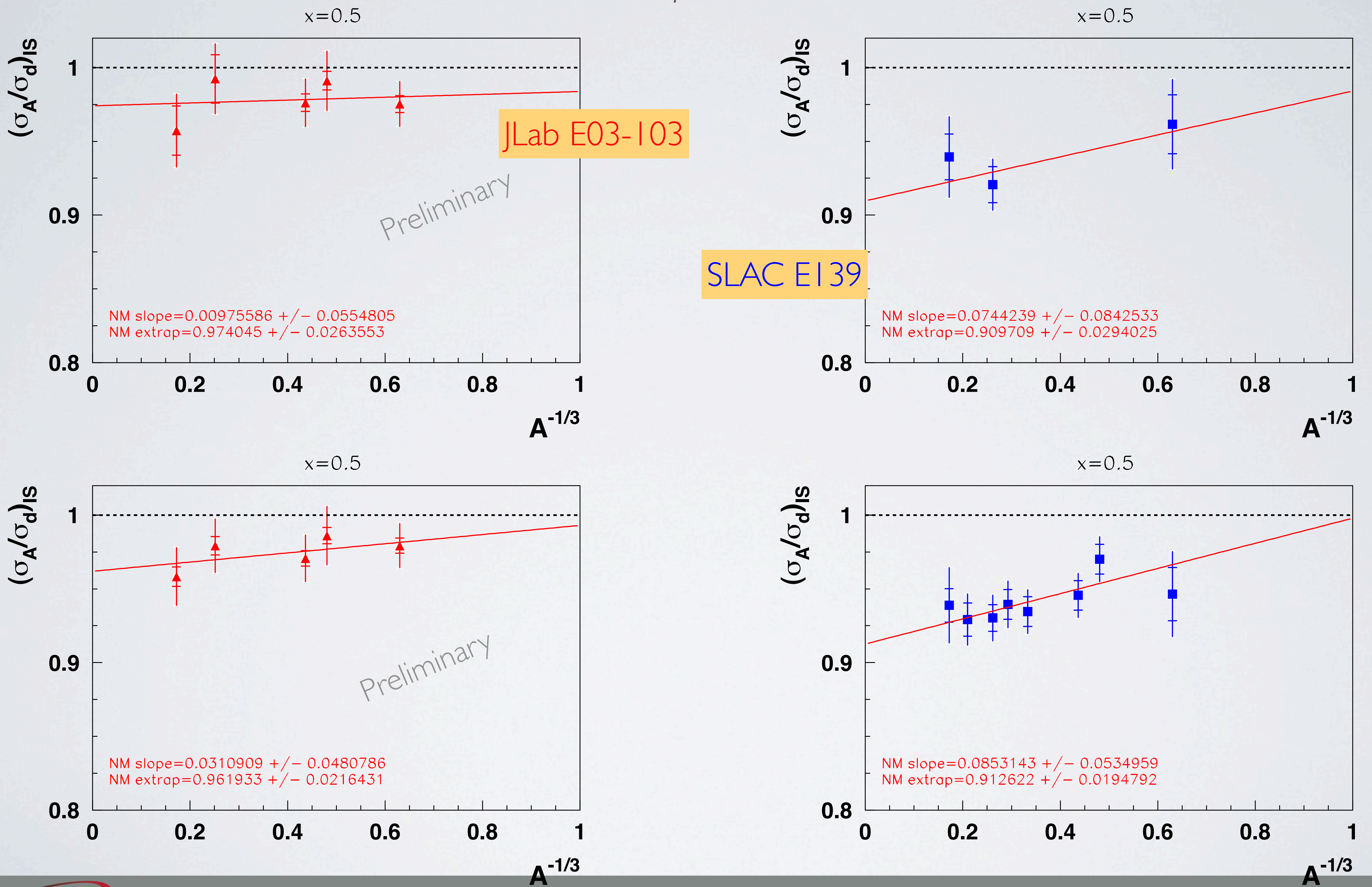

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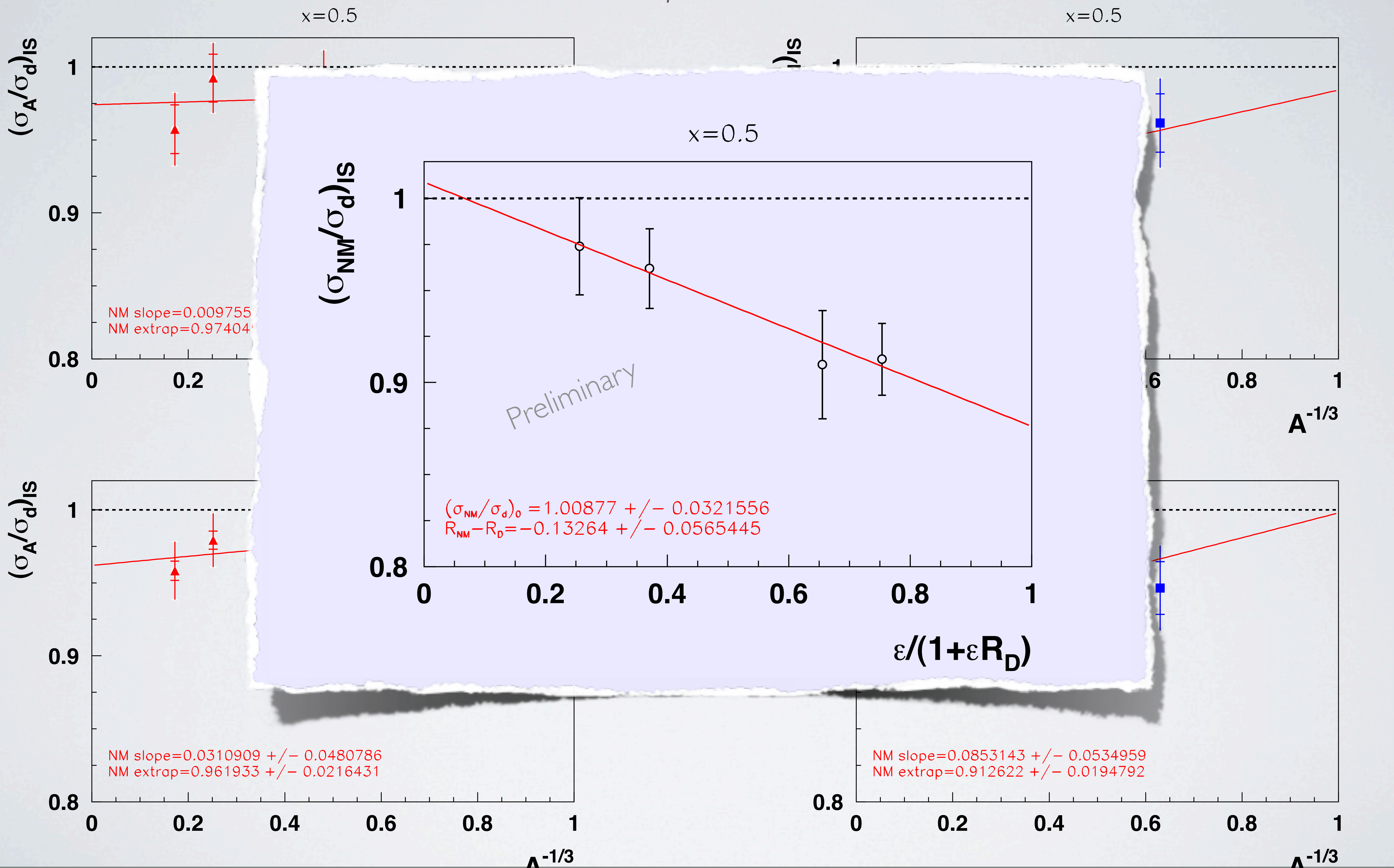
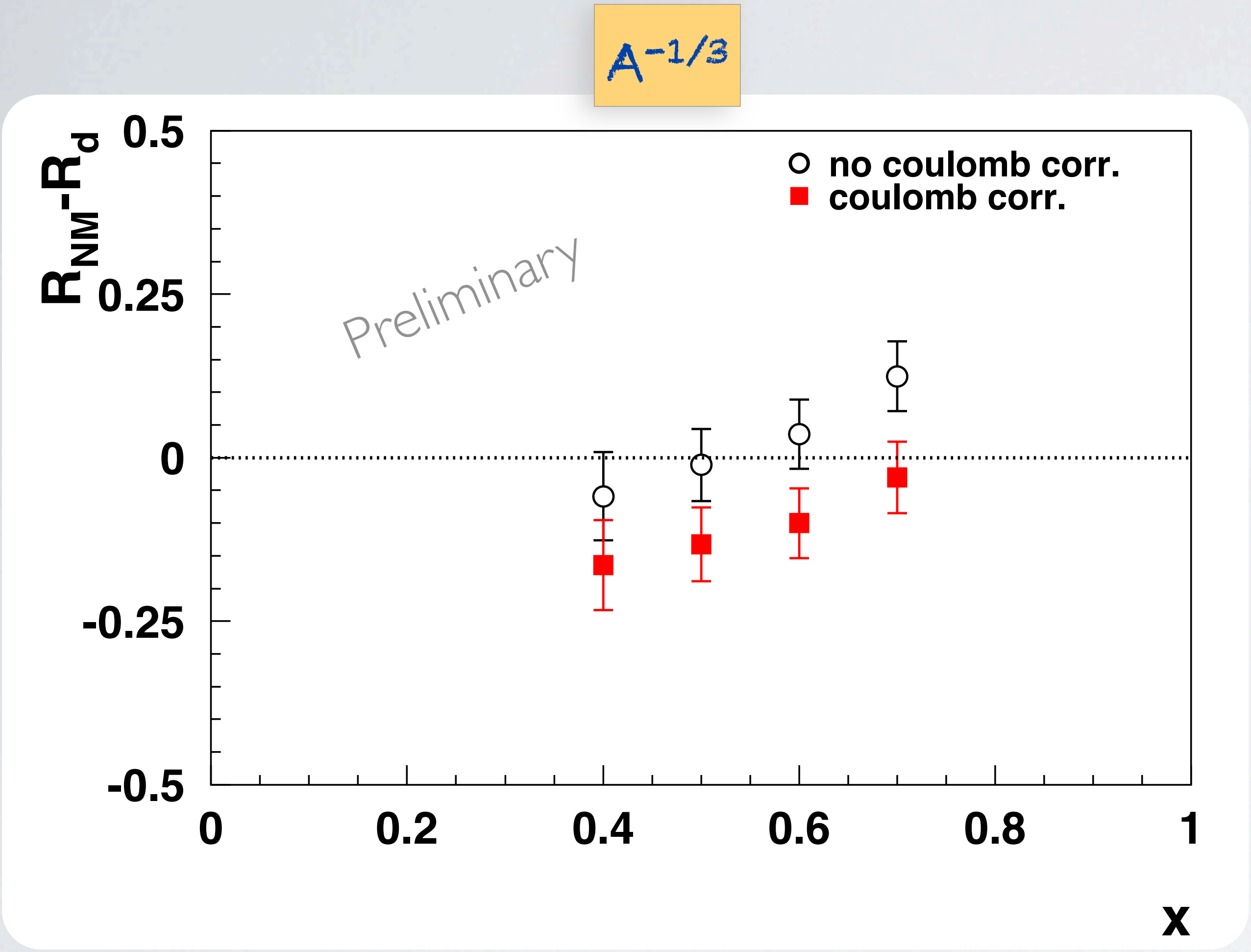
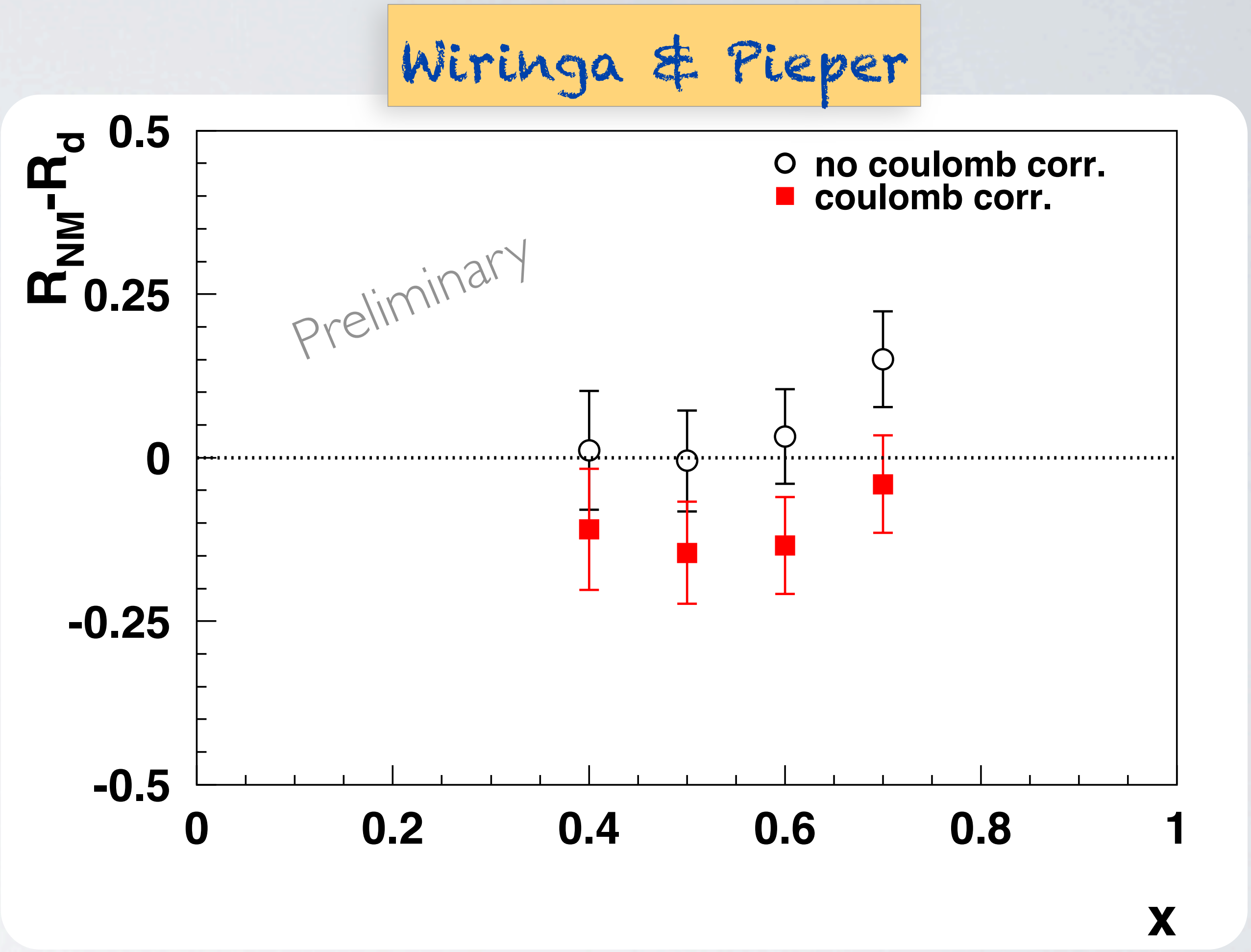


X-DEPENDENCE OF $R_{NM}-R_D$





After Coulomb correction, indication of a small but non-negligible nuclear dependent of R and $R_{NM} < R_D$

X-DEPENDENCE OF σ_{NM}/σ_D AT $\varepsilon'=0$

$$\frac{d\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T(x,Q^2) + \cancel{\varepsilon\sigma_L(x,Q^2)}\right]$$

at ε’=0= ε

$$\frac{\sigma_{(NM)}}{\sigma_{(D)}} \xrightarrow{\varepsilon\to 0} \frac{\sigma_{T\,(NM)}}{\sigma_{T\,(D)}}$$

and

$$F_1(x,Q^2) = \frac{K}{4\pi^2\alpha} M\sigma_T(x,Q^2)$$

$$\boxed{\frac{\sigma_{(NM)}}{\sigma_{(D)}} \xrightarrow{\varepsilon\to 0} \frac{F_{1\,(NM)}}{F_{1\,(D)}}}$$

$$2xF_1(x) = x\sum_q e_q^2(q(x)+\bar{q}(x))$$

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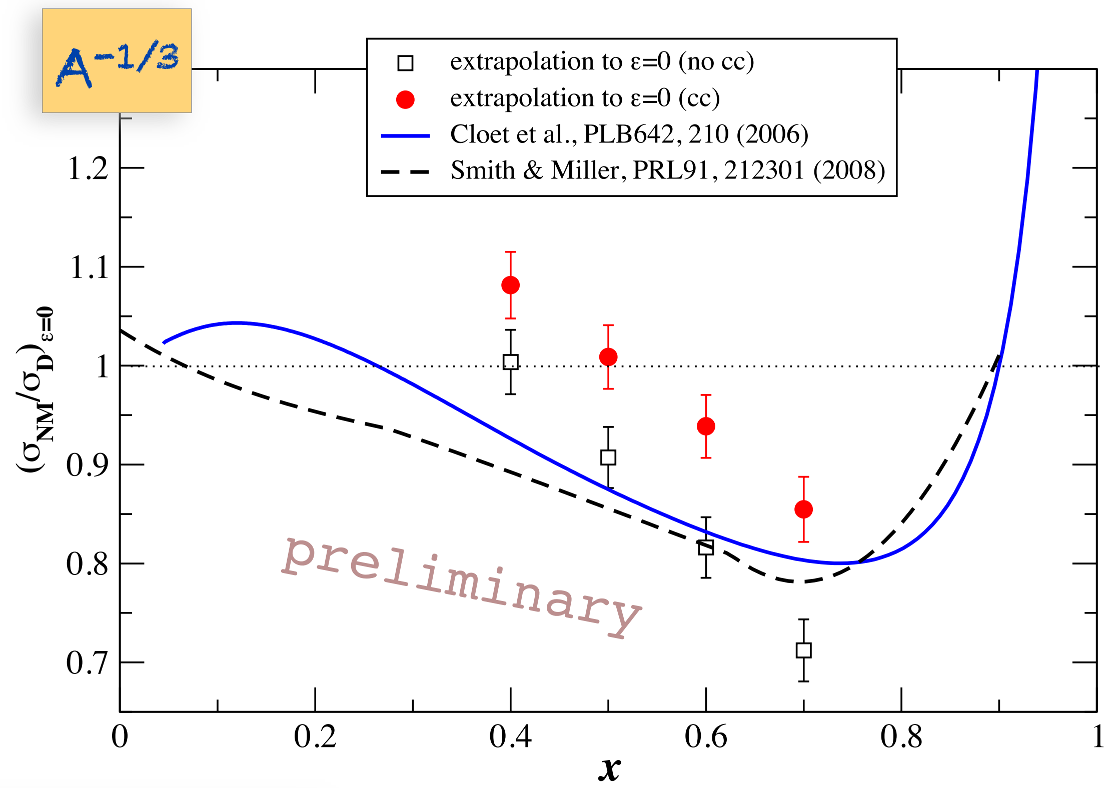
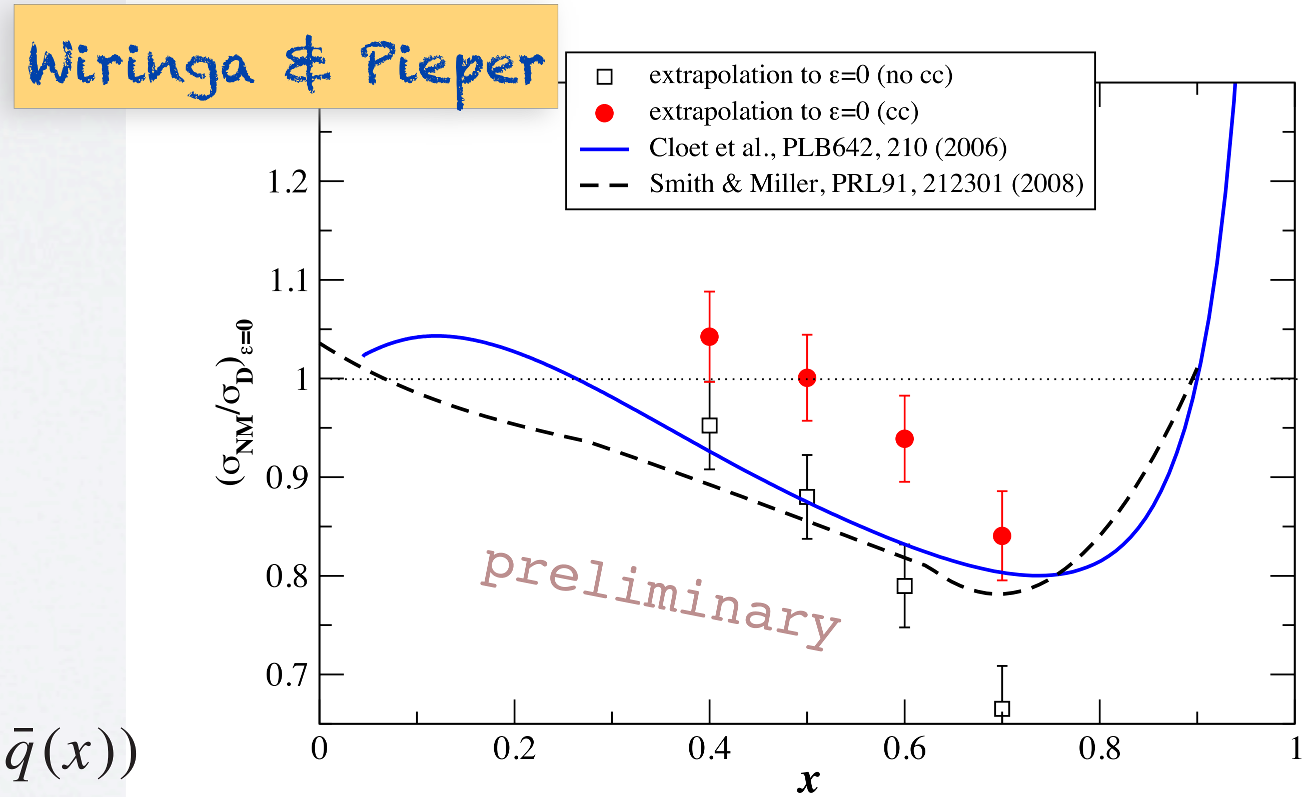
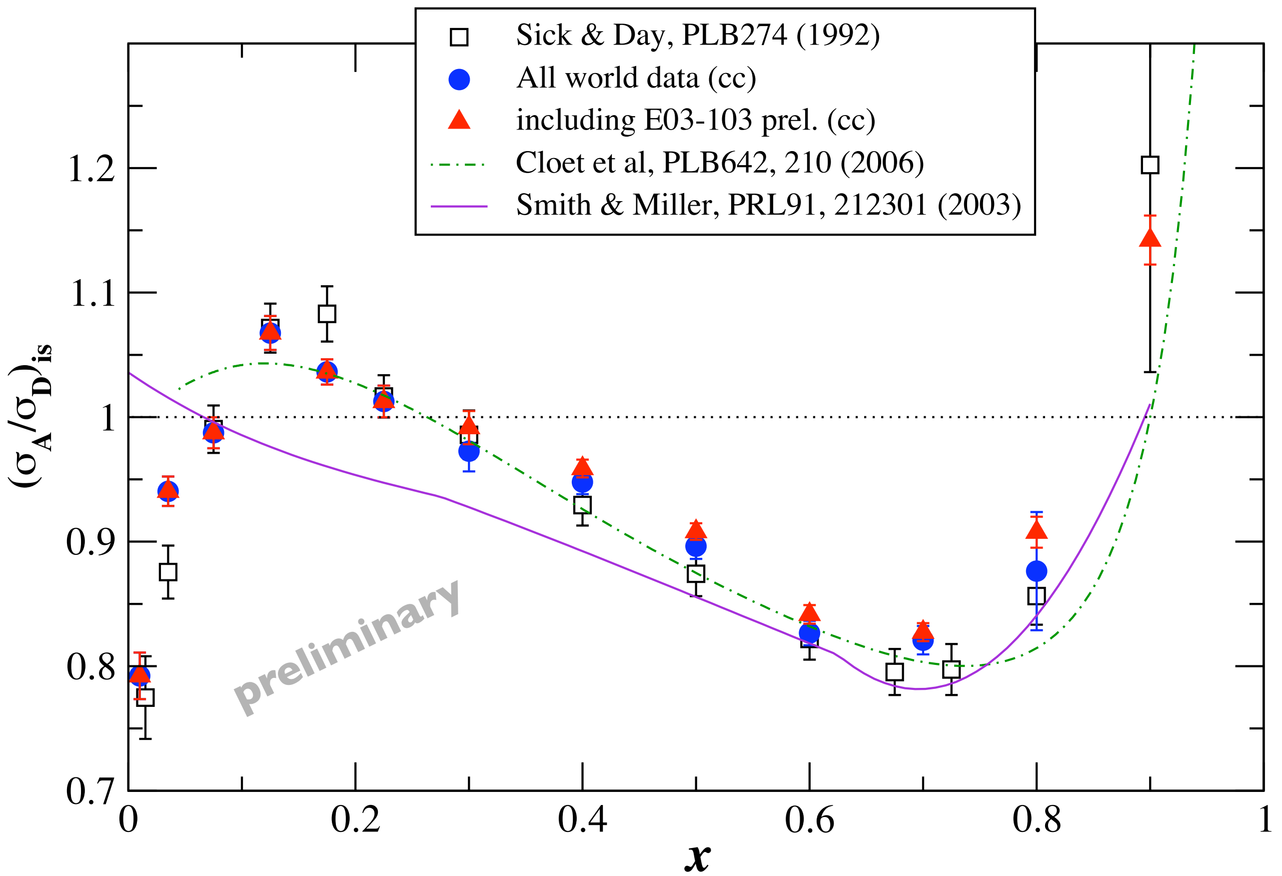


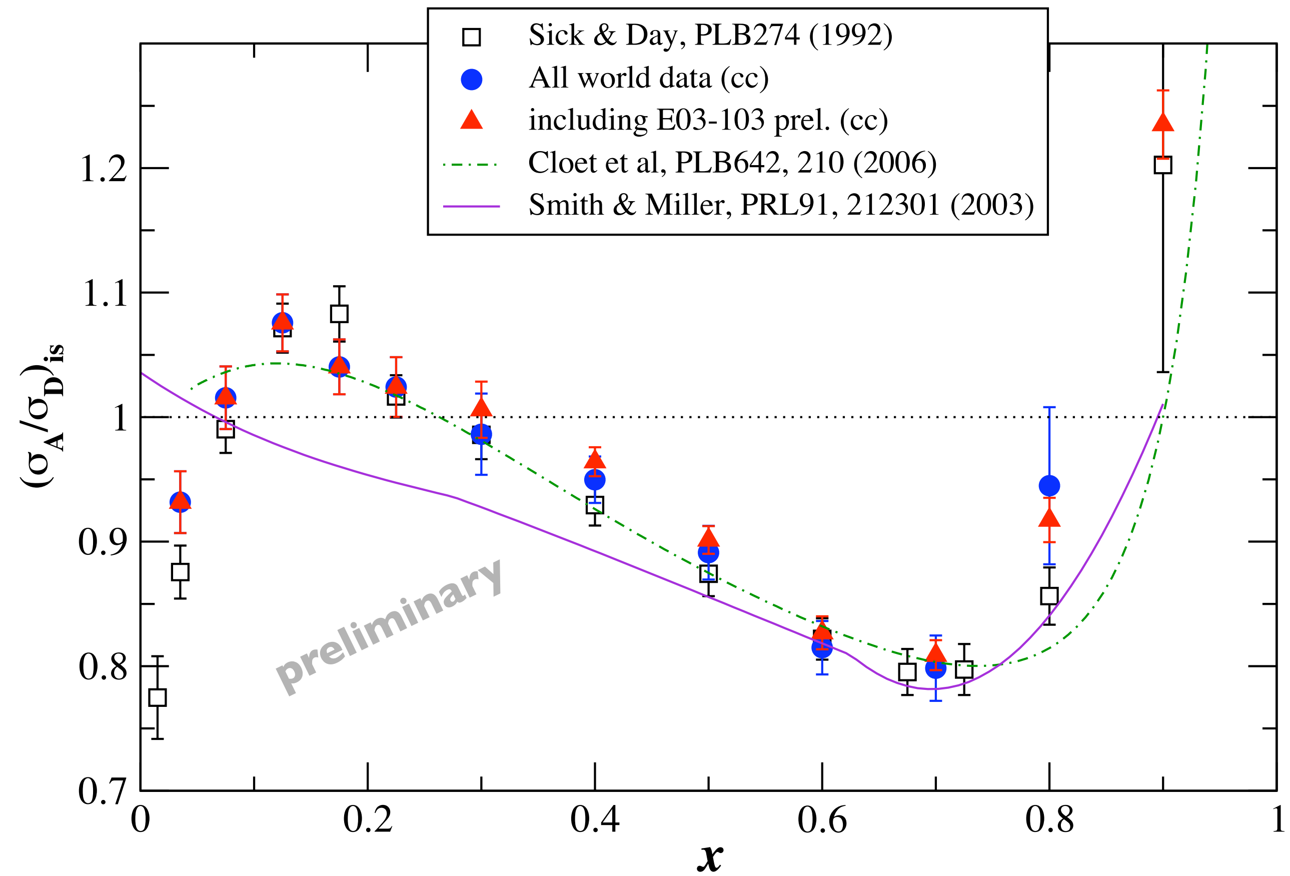


EMC EFFECT IN NUCLEAR MATTER

From $A^{-1/3}$ dependence



From ρ-dependence



using same method as in Sick & Day

World data: large ε → L and T parts of the cross section enter with the same kinematic factor

SUMMARY

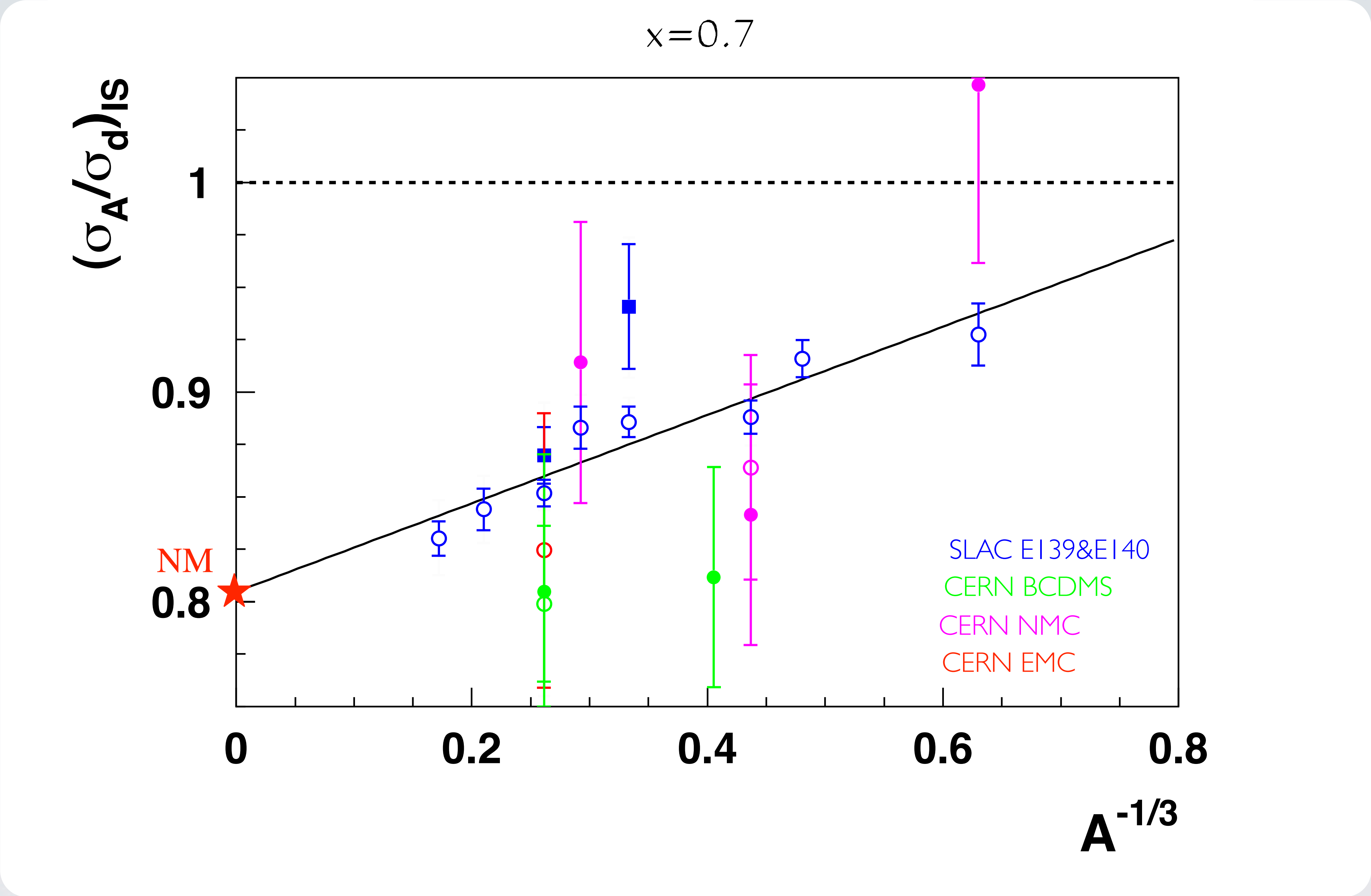
- Heavy nuclei at low ε data from JLab E03-103 and Coulomb distortion:
  - *affects the extrapolation to nuclear matter which is key for comparison with theoretical calculations*
  - *has a real impact on the A-dependence of R: clear ε-dependence*
  - *Some of these conclusions depends mostly on the re-analysis of the SLAC data including Coulomb corrections.*
  - *Hint of different nuclear effects in F_1 and F_2: need theoretical calculations which don't assume the Callan-Gross relation: $F_2 = 2x F_1$*
  - *Publication in preparation*
- R_A proposal at JLab 12 GeV in preparation

Extra slides

EXTRAPOLATION TO NUCLEAR MATTER

Exact calculations of the EMC effect exist:

- for light nuclei
- for nuclear matter



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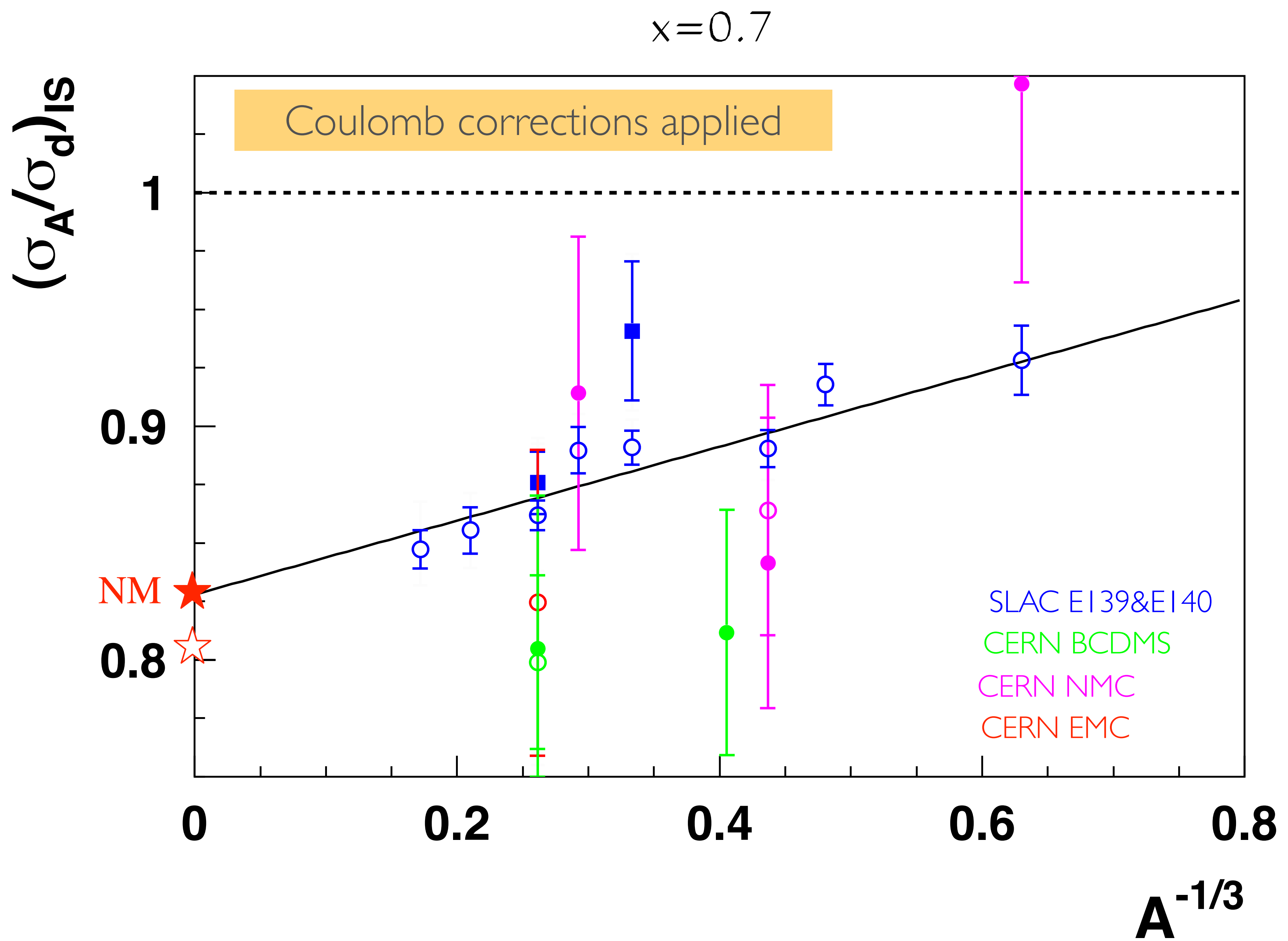

Non-negligible effects on SLAC data

EXTRAPOLATION TO NUCLEAR MATTER

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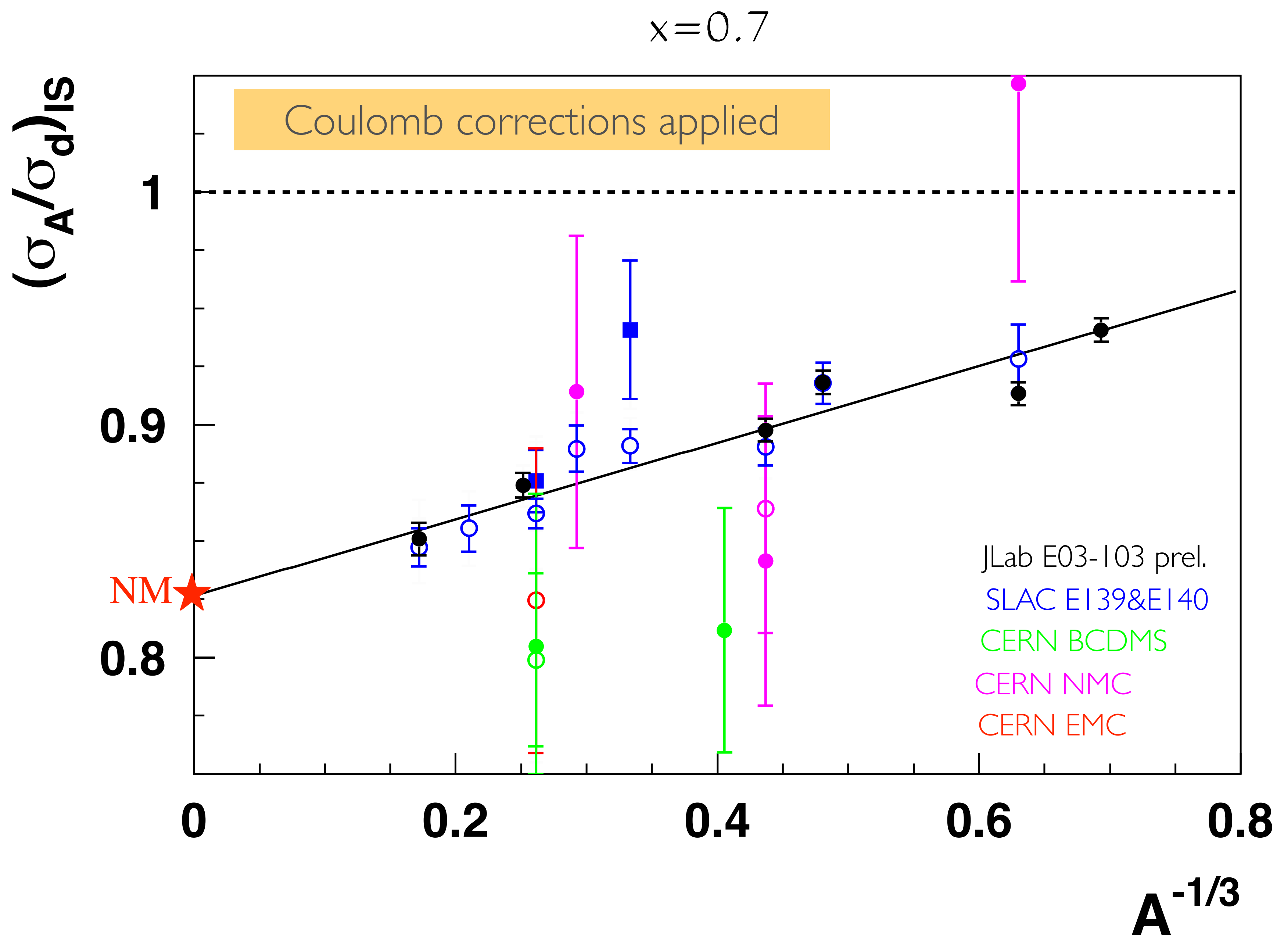
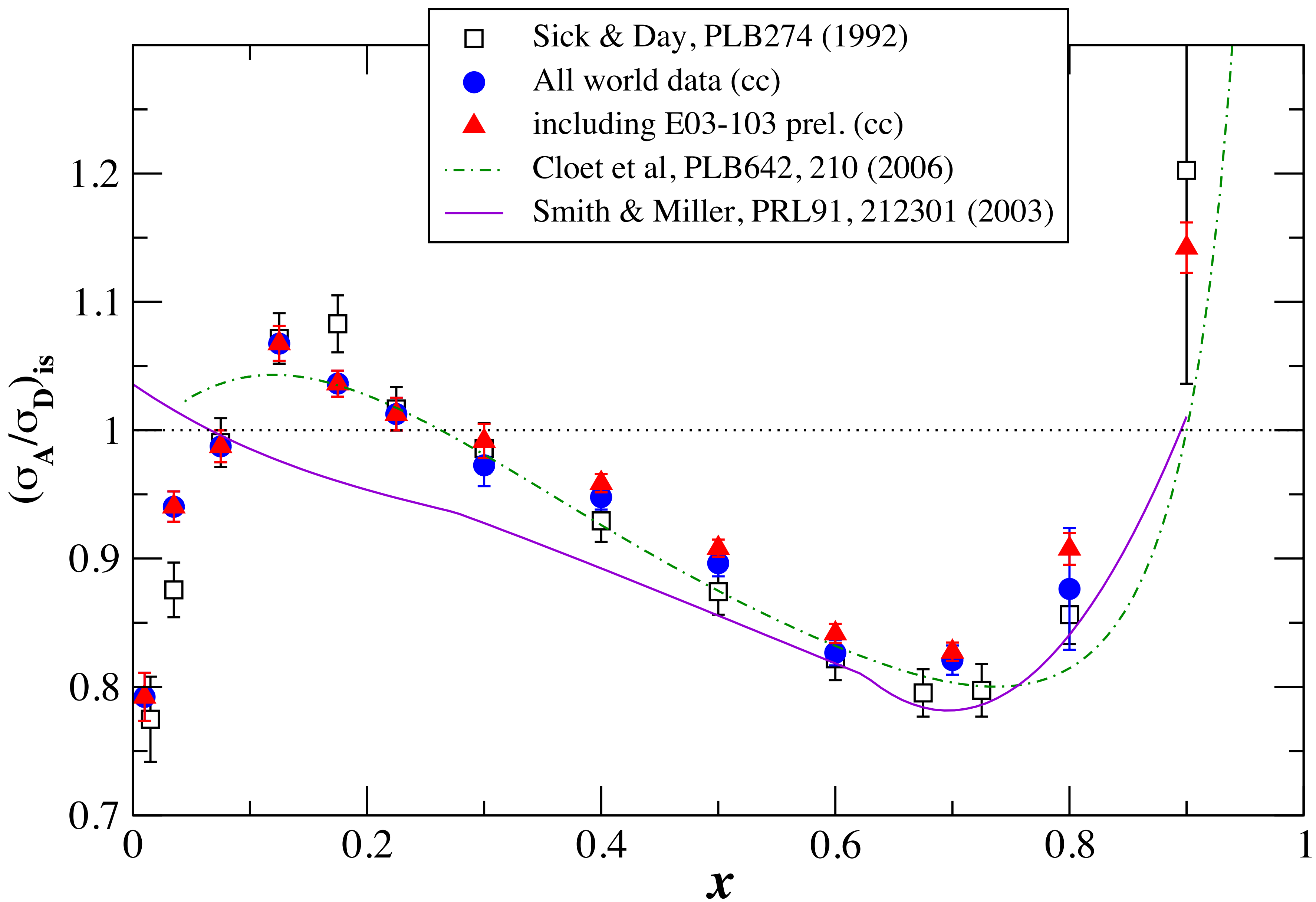
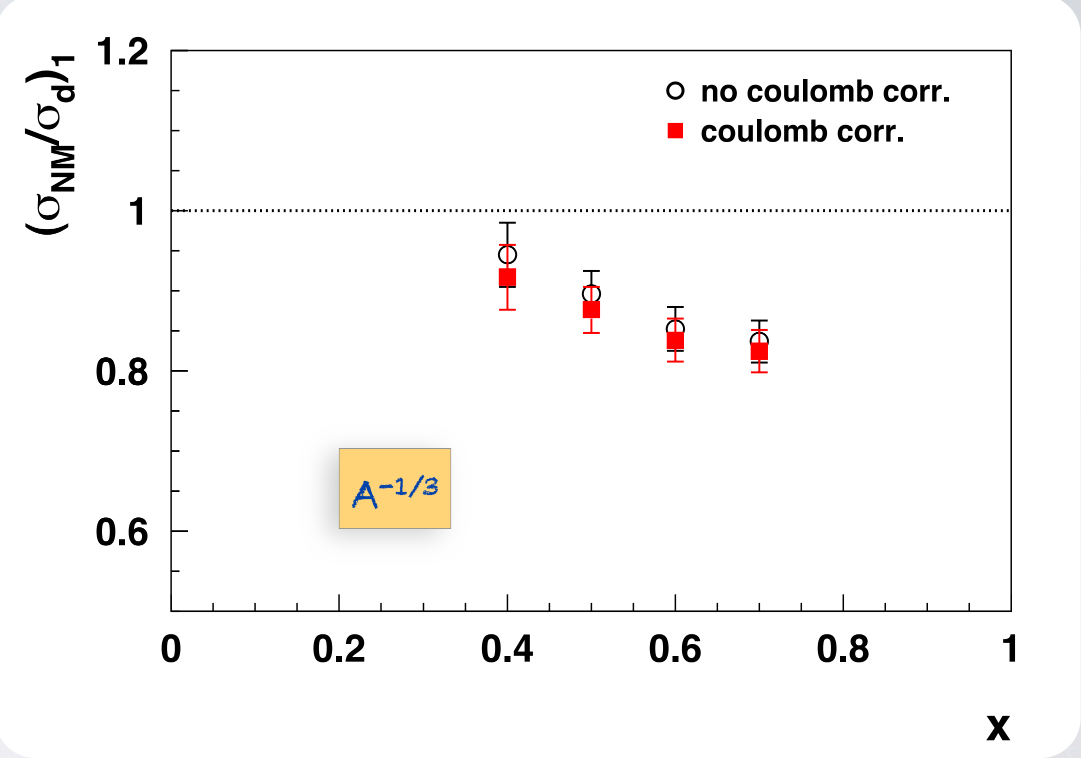


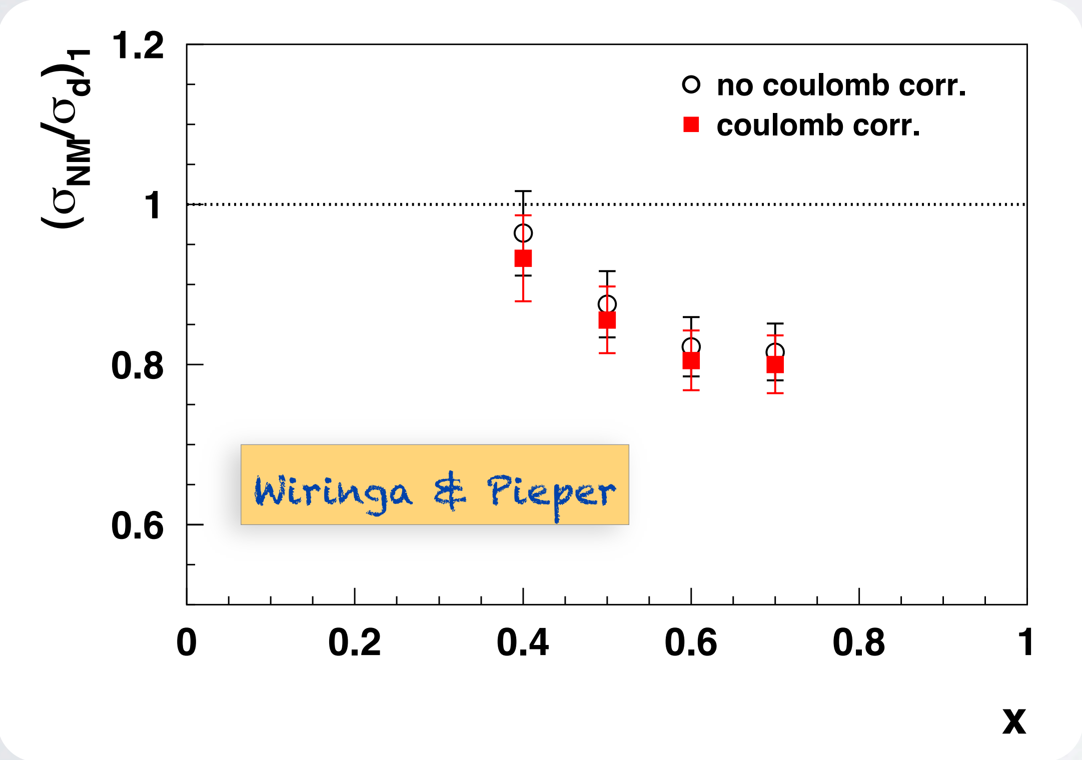
EXTRAPOLATION TO NUCLEAR MATTER

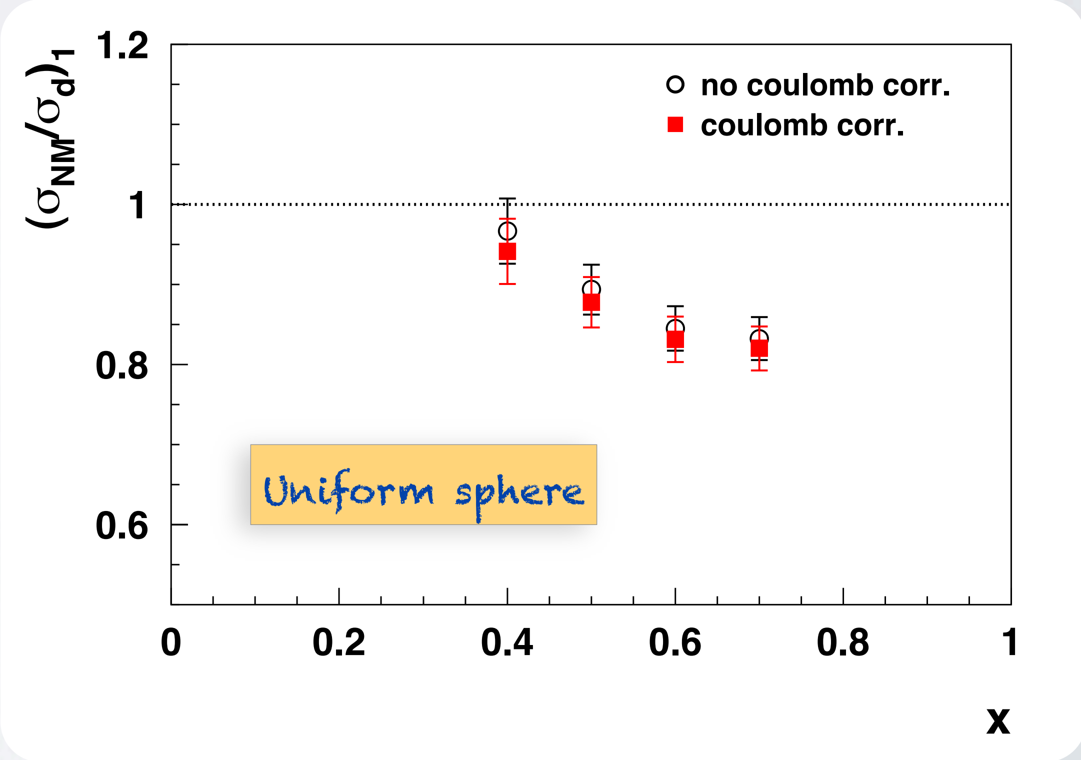
EMC effect in nuclear matter



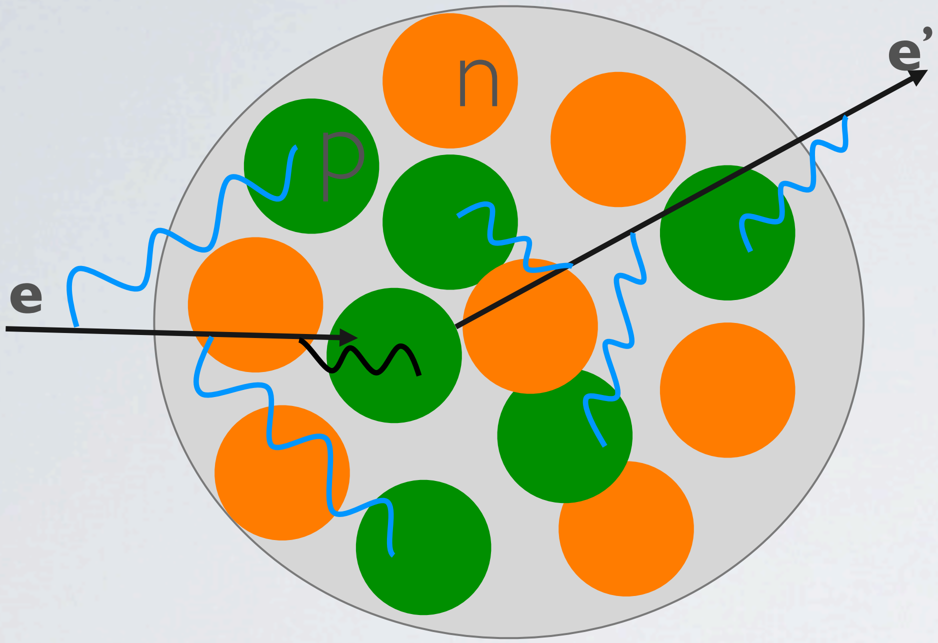
X-DEPENDENCE OF σ_{NM}/σ_D AT $\epsilon'=1$







COULOMB DISTORTION

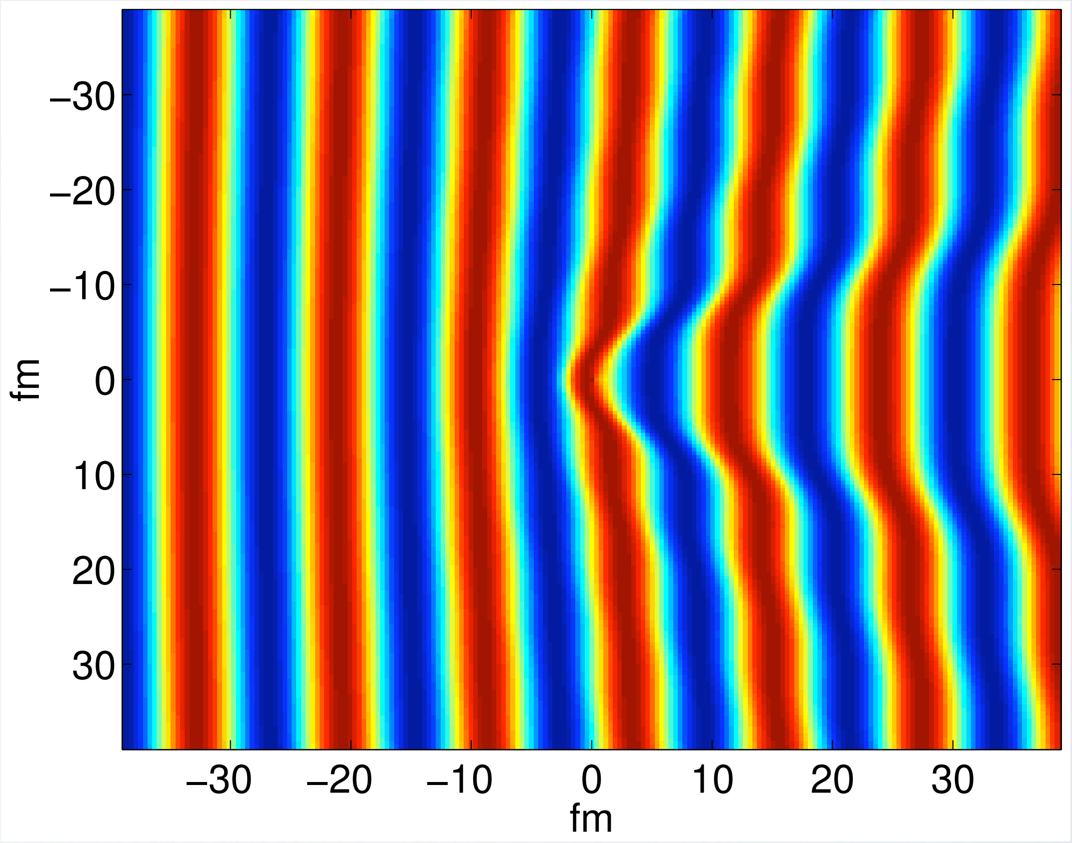


Exchange of **one or more (soft) photons** with the nucleus, in addition to the **one hard photon** exchanged with a nucleon

Incident (scattered) electrons are accelerated (decelerated) in the Coulomb well of the nucleus.

$$\cancel{\sigma_{tot}^{PWBA} = \sigma_{Mott}\, S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta)}$$

Fig. from **A. Aste** at Mini-Workshop on Coulomb Distortion, JLab May 2005



Coulomb Distortion could have the same kind of impact as TPE, but gives also a correction that is A-dependent.

HOW TO CORRECT FOR COULOMB DISTORTION ?

$$\cancel{\sigma_{tot}^{PWBA} = \sigma_{Mott}\, S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta)} \Rightarrow$$

σ_{tot}^{DWBA}

- Focusing of the electron wave function
- Change of the electron momentum

Effective Momentum Approximation (EMA)

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)

$$\left.\begin{array}{l} - \; E \rightarrow E + V \\ - \; E_p \rightarrow E_p + V \end{array}\right\} \; Q^2_{eff} = 4(E + \bar{V})(E_p + \bar{V}) \sin^2(\frac{\theta}{2})$$

1st method

$$S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta) \longrightarrow S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)$$

$$\boxed{\sigma_{tot}^{CC} = \sigma_{Mott} \cdot S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)}$$

$\Leftrightarrow$

2nd method

$$S_{tot}^{PWBA}(|\vec{q}|, \omega, \theta) \longrightarrow S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)$$

$$\sigma_{Mott}^{eff} = 4\alpha^2 \cos^2(\theta/2)(E_p + \bar{V})^2 / Q^4_{eff}$$

$$F^i_{foc} = \frac{E + \bar{V}}{E}$$

$$\boxed{\sigma_{tot}^{CC} = (F^i_{foc})^2 \cdot \sigma_{Mott}^{eff} \cdot S_{tot}^{PWBA}(|\vec{q}_{eff}|, \omega, \theta)}$$

HOW TO CORRECT FOR COULOMB DISTORTION ?

$$\cancel{\sigma^{PWBA}_{tot} = \sigma_{Mott}\, S^{PWBA}_{tot}(|\vec{q}|, \omega, \theta)}$$

⇨

σ^{DWBA}_{tot}

- Focusing of the electron wave function
- Change of the electron momentum

Effective Momentum Approximation (EMA)

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)

– E → E + V

– E_p → E_p + V

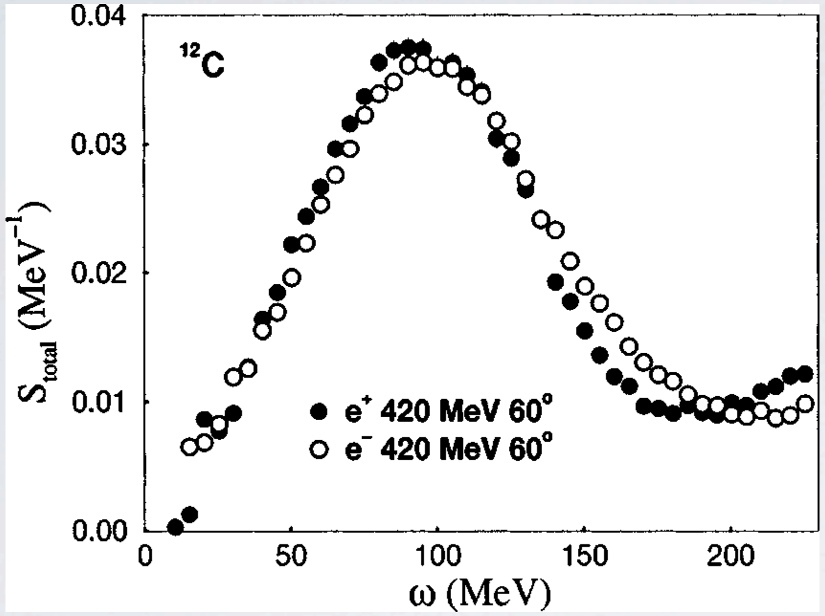
$$Q^2_{eff} = 4(E + \bar{V})(E_p + \bar{V})\sin^2(\frac{\theta}{2})$$

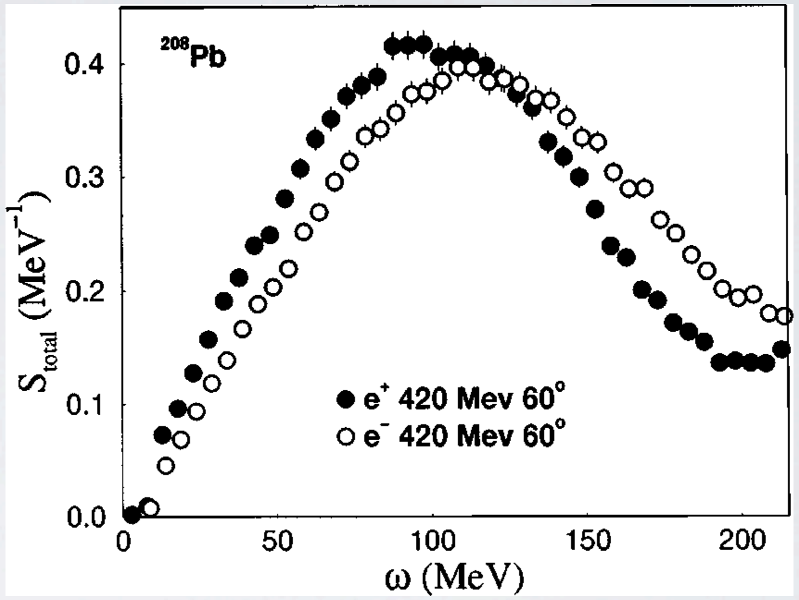
One-parameter model depending only on the effective potential seen by the electron on average.

$$F^i_{foc} = \frac{E + \bar{V}}{E}$$

$$\sigma^{CC}_{tot} = \sigma_{Mott} \cdot S^{PWBA}_{tot}(|\vec{q}_{eff}|, \omega, \theta) \Leftrightarrow \sigma^{CC}_{tot} = (F^i_{foc})^2 \cdot \sigma^{eff}_{Mott} \cdot S^{PWBA}_{tot}(|\vec{q}_{eff}|, \omega, \theta)$$

COULOMB DISTORTION IN QE SCATTERING





Gueye *et al.*, PRC60, 044308 (1999)

$$\tilde{k} = k - V(z)$$

$$V(r) = -\frac{3\alpha(Z-1)}{2R} + \frac{\alpha(Z-1)}{2R}\left(\frac{r}{R}\right)^2$$

$$R = 1.1A^{1/3} + 0.86A^{-1/3}$$

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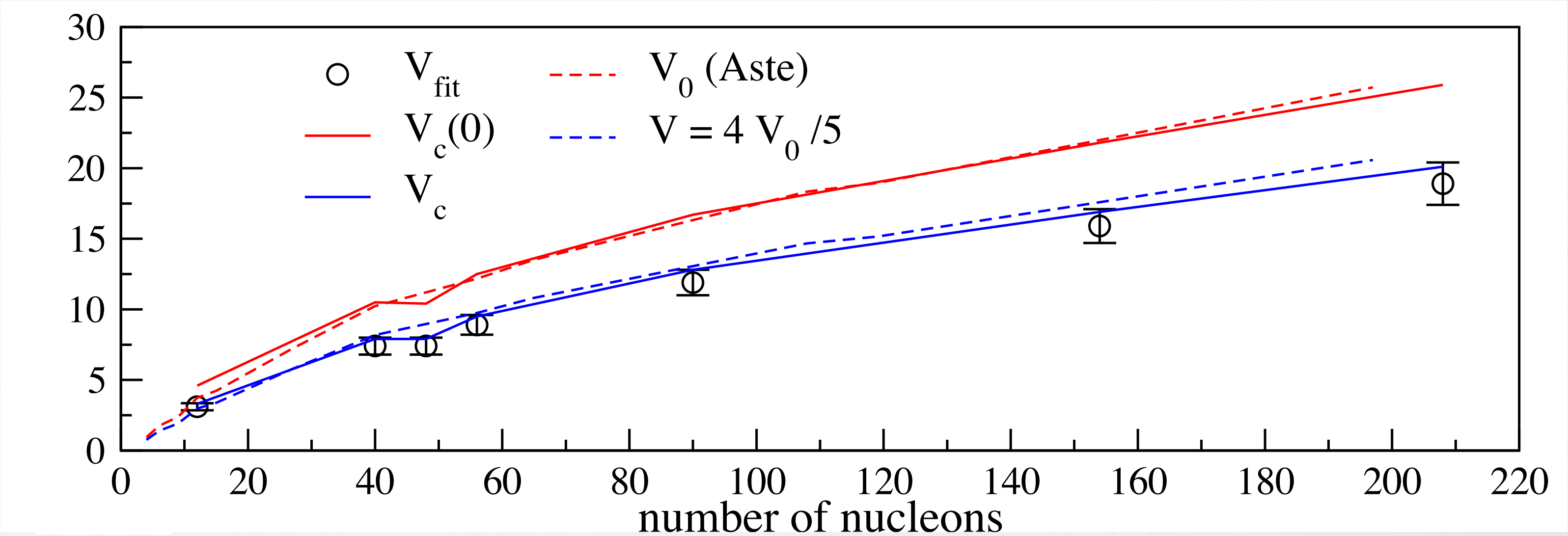
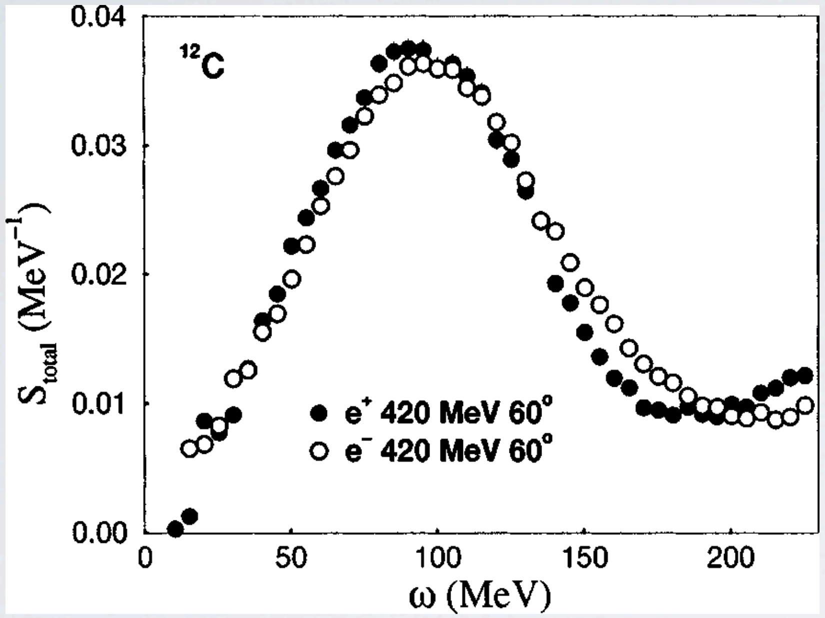
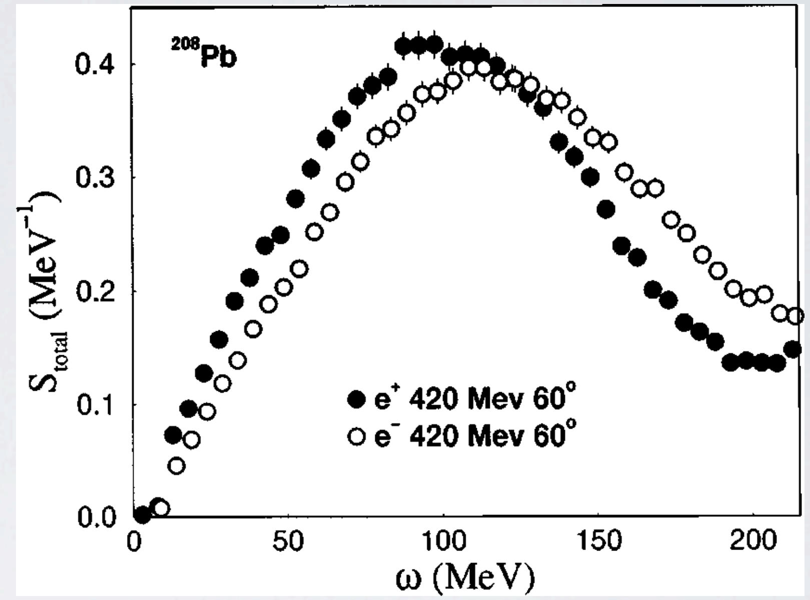


COULOMB DISTORTION IN QE SCATTERING





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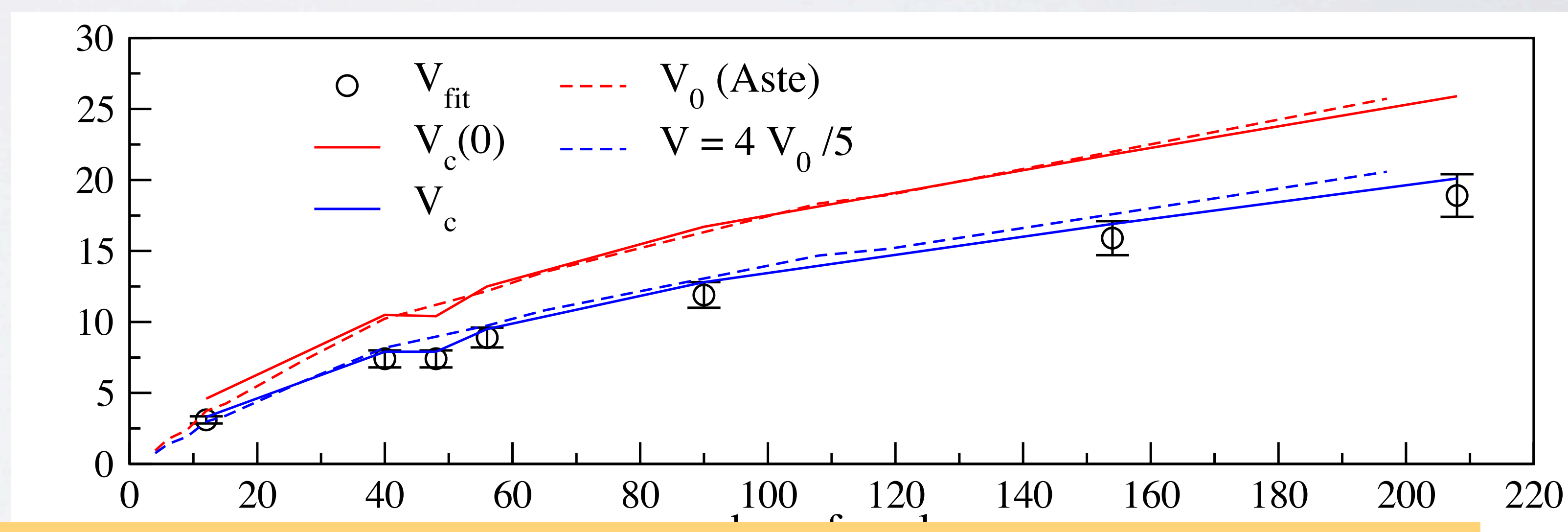
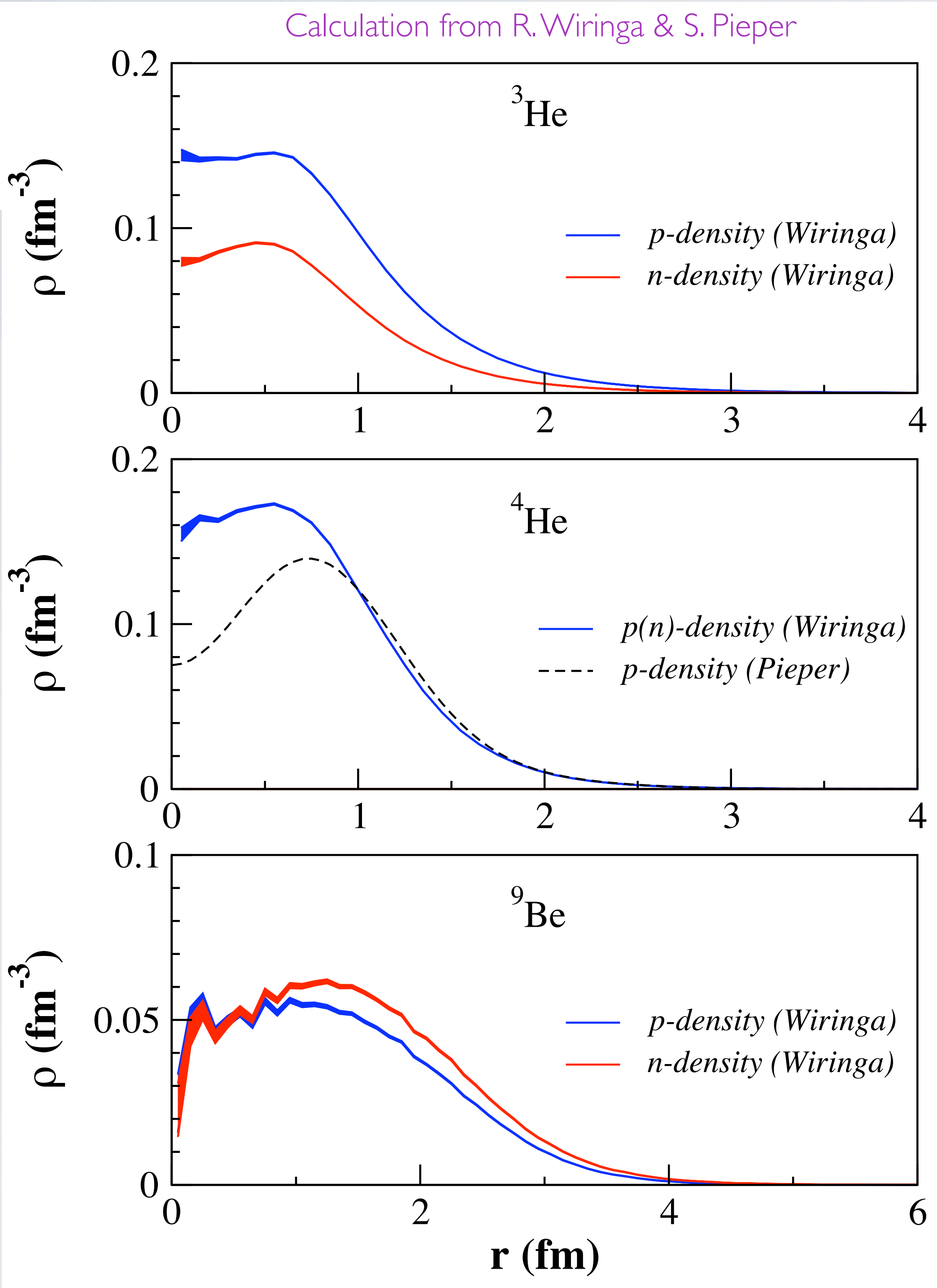
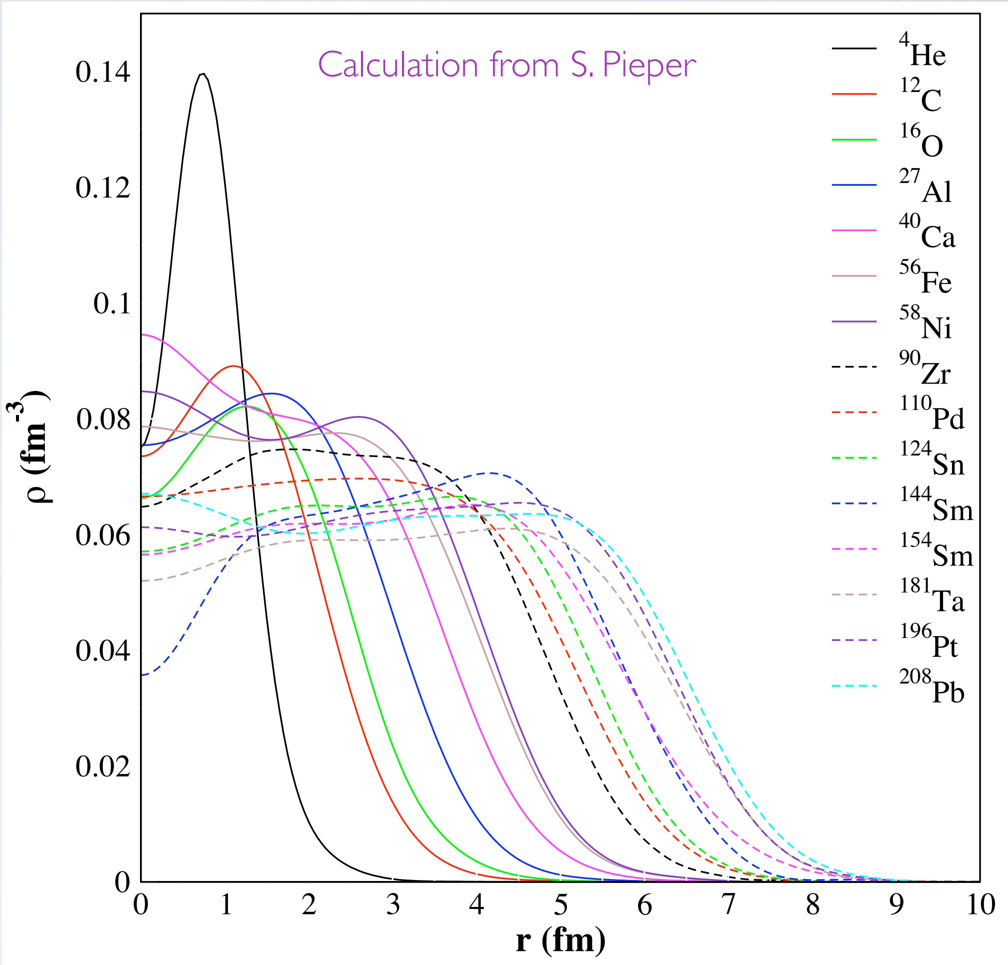


Coulomb potential established in Quasi-elastic scattering regime !

DENSITY CALCULATIONS





Average density:

$$\langle \rho_{n,p} \rangle = \frac{\int \rho_{n,p}^2 d^3r}{\int \rho_{n,p} d^3r}$$

$$\langle \rho_p \rangle + \langle \rho_n \rangle = \langle \rho_A \rangle \xrightarrow{\text{finite proton size correction}} \langle \rho_A \rangle \cdot \left(\frac{\langle r \rangle}{r_{eff}} \right)^3$$

with $r_{eff} = \sqrt{\langle r \rangle^2 + 0.9^2}$